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PROGRESS REPORT ON ALECTO AND CYCLOPS II

(U)

by

Ronald F. Vetter

Propulsion Development Department

ABSTRACT. This report covers work done on propellant formulations, motor design and testing, and igniter design for the Alecto and Cyclops II silver iodide-generating rocket motors.

Propellant studies included tests on various Nitrasol and fluorocarbon propellants for extrusion production. Studies on these propellants were discontinued in favor of cast, nitroplasticized, polybutadiene-acrylic acid (PBAA) binder formulations that were found to be safer. Design and fabrication of the Alecto unit culminated in a 2 1/2-inch-diameter cast PBAA grain packaged in a modified M123 photo-flash canister. The Cyclops II unit had drag fins and an 8-inch-outside-diameter motor package.

Tests were performed on only a few of each type of unit because the delivery schedules necessitated design freezes. However, static firings to check the ignition system, the heat liner system, and the inhibiting system were made. Some units were vibration-tested and others subjected to 5-foot-drop tests before firing.

All units showed that they were applicable for flight use, and 390 Alecto units and 24 Cyclops II units were ready for use against a hurricane by September 1962. (UNCLASSIFIED)

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U.S. NAVAL ORDNANCE TEST STATION

China Lake, California

May 1963

AL

U. S. NAVAL ORDNANCE TEST STATION

AN ACTIVITY OF THE BUREAU OF NAVAL WEAPONS

C. BLENMAN, JR., CAPT., USN
Commander

WM. B. MCLEAN, PH.D.
Technical Director

FOREWORD

This report details experimental results of studies on propellant formulations designed to yield silver iodide salt particles as combustion products. The engineering and pilot production was done on an extremely short time scale, but motors of two designs were delivered in quantity by the end of the reporting period.

The work was done as part of Bureau of Naval Weapons Task Assignment FASS-00-016/216-1/R004-0201, and the report was reviewed for technical accuracy by R. A. Miller and J. R. Sims.

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The author is indebted to Jack M. Pakulak, Jr., of the Production Evaluation Branch, Propulsion Development Department, for his thermal study of CY-21, at present the optimum propellant carrier.

INTRODUCTION

For years, various methods of disseminating silver iodide in the clouds (cloud seeding) to control weather conditions have been under investigation. In 1961, the idea of generating silver iodide in a propellant carrier was investigated at the U. S. Naval Ordnance Test Station (NOTS). The first of these propellant carriers was a Nitrasol-binder propellant that performed satisfactorily, as evidenced by the seeding operations against Hurricane Esther in 1961,[1] despite (1) complications of delay fuzes, (2) ignition through a long tube, (3) other ignition and gas sealing problems, and (4) cartridge loading.

Since Nitrasol propellants were temporarily banned from Navy use for safety reasons, polyurethane propellants, which had previously been examined for use in Cyclops units, were further tested. However, the polyurethane system contained aluminum fuel and ammonium perchlorate, which was not desirable because of the reduction in silver iodate loading, generation of chloride-containing products, and the tendency to be oxygen poor. A propellant system incorporating an energetically plasticized polyurethane binder was also investigated, in late 1961.[2] No further work was done at that time, because of lack of funds.

In April 1962, funds were made available for research and development to culminate in the fabrication of two new salt generator prototypes for Project Stormfury: a large unit, Cyclops II, and a small unit, Alecto (Fig. 1).

Since Nitrasol propellant had previously been used successfully, further work, particularly safety testing, was done coincidentally with constant efforts to have the Nitrasol processing ban lifted to allow processing of material for Cyclops II and Alecto.

[1] U. S. Naval Ordnance Test Station. Project Cyclops. An Experiment in Hurricane Modification, by Pierre Saint-Amand and Graeme W. Henderson. China Lake, Calif., NOTS, May 1962. 34 pp. (NOTS TP 2751.)

[2] Results of this work are presented in Silver Iodide Generator Propellant (U), by Henry Sampson, Ronald Vetter, and Martin Kaufman. China Lake, Calif., NOTS, 9 November 1961 (IDP 1442), CONFIDENTIAL.

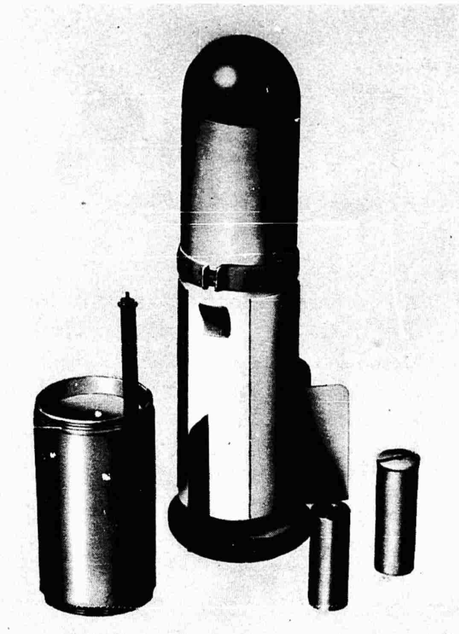


FIG. 1. Cyclops II and Alecto Motors and Assemblies.

PROPELLANT FORMULATION STUDIES

A new propellant was needed to carry silver iodate in Alecto and Cyclops II, so studies were started on a new series of propellants, designated CY (Table 1). Nitrasol, fluorocarbon, and polybutadiene-acrylic acid (PBAA) propellants were formulated, tested, and assigned CY numbers at random. As each propellant was formulated, its properties were checked, and modifications were made to change its characteristics to obtain the optimum carrier. These changes and modifications were assigned new CY numbers.

NITRASOL PROPELLANTS

Since the Nitrasol formulation (P-65) used in Cyclops I was not entirely characterized or believed to be optimum, several more highly loaded (with silver iodate) formulations were devised and tests performed on each. The first formulations based on Nitrasol binders exhibited very poor physical properties, as shown in Table 2. The Nitrasol propellants in the CY series are CY-1, CY-2, CY-3, CY-4, CY-5, CY-7, CY-8, and CY-15. Because of the continuing ban on Nitrasol processing, no motors were loaded with Nitrasol propellants.

TABLE 1. COMPOSITION OF C[illegible] FORMULATIONS

Propellant ingredient	Formulation, weight %												
	CY-1	CY-2	CY-3	CY-4	CY-5	CY-6	CY-7	CY-8	CY-9	CY-10	CY-11	CY-12	CY-13
PNC NPPK[a]	5.00	5.83	5.00	10.00	1.96		9.00	6.50	16.25				8.50
TEGN[b]	10.00		10.00	15.00									
Silver iodate	85.00	82.52	83.00	75.00	83.33	85.00	75.00	75.00		70.00		90.00	
TMETN[c]		11.65				3.50						2.50	
Candelilla wax			2.00		0.49		0.25	0.25	0.625				
PETriN					6.86		14.50	12.00	30.00				21.00
Nitrocellulose (fibrous)					4.90		1.00	1.00	2.50				
Resorcinol					0.49		0.25	0.25	0.625				0.50
Lecithin					1.97								
Aluminum 123[d]								5.00	12.50			1.50	5.00
Lead iodate									37.50		70.00		65.00
Magnesium no. 16[d]										10.00	10.00		
Teflon no. 6										14.00	14.00		
Teflon no. 7													
Viton A										5.00	5.00		
Viton A-HV													
Carbon black (P-33)										1.00	1.00		
MAPO[e]						0.327						0.170	
Butarez CTL II[f]						11.173						5.830	
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

[a] Plastisol nitrocellulose with 5% ethyl centralite from the Naval Propellant Plant.
[b] Triethyleneglycol dinitrate.
[c] Trimethylolethane trinitrate.
[d] Atomized.
[e] Tris[1-(2-methyl)aziridinyl]phosp
[f] Carboxylated linear polybutadien

TABLE 1. Composition of CY Propellant Formulations

Formulation, weight %																	
CY-5	CY-6	CY-7	CY-8	CY-9	CY-10	CY-11	CY-12	CY-13	CY-14	CY-15	CY-16	CY-17	CY-18	CY-19	CY-20	CY-21	P-65
1.96	....	9.00	6.50	16.25	....	....	....	8.50	....	5.50	....	....	....	....	....	....	8.50
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
83.33	85.00	75.00	75.00	....	70.00	....	90.00	....	....	75.00	80.00	80.00	80.00	87.50	91.00	89.00	65.00
....	3.50	....	....	....	....	....	2.50	....	....	....	....	....	....	2.50	2.50	2.50	....
0.49	....	0.25	0.25	0.625	....	....	....	....	....	....	....	....	....	....	....	....	....
6.86	....	14.50	12.00	30.00	....	....	....	21.00	....	14.20	....	....	....	....	....	....	21.00
4.90	....	1.00	1.00	2.50	....	....	....	....	....	....	....	....	....	....	....	....	....
0.49	....	0.25	0.25	0.625	....	....	....	0.50	....	0.30	....	....	....	....	....	....	0.50
1.97	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
....	....	....	5.00	12.50	....	....	1.50	5.00	....	5.00	....	....	8.00	3.50	....	1.50	5.00
....	....	....	....	37.50	....	70.00	....	65.00	65.00	....	....	....	....	....	....	....	....
....	....	....	....	....	10.00	10.00	....	....	10.00	....	8.00	8.00	....	....	....	....	....
....	....	....	....	....	14.00	14.00	....	....	....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	9.00	....	5.00	5.00	5.00	....	....	....	....
....	....	....	....	....	5.00	5.00	....	....	15.00	....	6.00	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	6.00	6.00	....	....	....	....
....	....	....	....	....	1.00	1.00	....	....	1.00	....	1.00	1.00	1.00	....	....	....	....
....	0.327	....	....	....	....	....	0.170	....	....	....	....	....	....	0.184	0.184	0.198	....
....	11.173	....	....	....	....	....	5.830	....	....	....	....	....	....	6.316	6.316	6.802	....
00.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Naval Propellant Plant.

[d] Atomized.

[e] Tris[1-(2-methyl)aziridinyl]phosphine oxide.

[f] Carboxylated linear polybutadiene.

TABLE 2. PHYSICAL PROPERTIES OF CY PROPELLANT F

Propellant	Grain type	Sensitivity tests[a]		Tensile tests				Burning			Heat of explosion cal/g
		Card gap (NOL)	Impact, 50% pt., cm	Elongation at max. tensile strength, %	Elongation at rupture, %	Max. tensile strength, psi	Modulus at 10% elongation	120 psig	535 psig	1,065 psig	
CY-1	extruded	....	55.0	4.0	......	96	2,400	....	0.124	0.425	415
CY-2	extruded	....	57.5	1.4	......	228	17,000	0.058	.179	.469	376
CY-3	extruded	....	103	3.5	......	104	2,900	....	.156	.338	558
CY-4	extruded	....	65.0	6.0	......	123	2,100	.074	.257	.448	648
CY-6	cast	....	......	21	......	30	240	.068	.150	.230	354
CY-7	extruded	....	30.9	2.2	......	230	11,000	.059	.242	.449	579
CY-8	extruded	....	28.3	2.7	......	197	7,000	.079	.201	.389	849
CY-9	extruded	....	37.1	1.0	......	209	2,200	.081	.148	.239	1,055
CY-10	extruded	....	62.5	5.5	22	972	17,300	.068	.137	.218	903
CY-11	..........[b]	....	......	......	......	....	....	....	....	....	....
CY-12	cast	3 no at zero	33.7	20	24	105	863	.125	.245	.364	497
CY-13	extruded	....	60	9	......	146	1,633	.051	.133	.210	830
CY-14	extruded	....	10/10 no	9	12	1,203	13,030	.034	.081	.122	798
CY-15	extruded	....	......	2.7	......	130	4,832	.075	.241	.397	....
CY-15	cast	....	24.4	7	......	102	1,552	.018	.232	.378	803
CY-16	extruded	....	156.5	13	19	640	4,843	.065	.155	.238	737
CY-17	extruded	....	118.8	9	......	672	7,482	.069	.145	.222	790
CY-18	..........[b]	....	......	......	......	....	....	....	....	....	....
CY-19	cast	....	43.5	10.2	15.4	105	1,030	.121	.223	.277	514
CY-20	cast	6 no at zero	42.5	35	41	70	480	.109	.191	.255	407
CY-21	cast	6 no at zero	30.2	21	24	52	385	.107	.192	.253	438
P-65	extruded	....	......	5.9	......	109	2,000	0.086	0.256	0.449	907

[a] Other sensitivity tests, electrostatic and friction, gave 10 no fires out of 10 tests on all propellants.
[b] Would not extrude. Also, CY-5 propellant would not extrude, and no data were available; therefore, it was omitted.
[c] When PbI is present, no PbI_2 is present. The reverse is also true.

PHYSICAL PROPERTIES OF CY PROPELLANT FORMULATIONS

ensile tests			Burning rate, in/sec			Heat of explosion, cal/g	Shore A-2 hardness	Density, g/cm^3	Residue of burning, theoretical max., %		
n e,	Max. tensile strength, psi	Modulus at 10% elongation	120 psig	535 psig	1,065 psig				AgI	PbI[c]	PbI_2[c]
	96	2,400	....	0.124	0.425	415	....	....	70.8	......	......
	228	17,000	0.058	.179	.469	376	....	....	68.1	......	......
	104	2,900	....	.156	.338	558	....	....	68.4	......	......
	123	2,100	.074	.257	.448	648	....	....	62.1	......	......
	30	240	.068	.150	.230	354	34	3.0339	70.8	......	......
	230	11,000	.059	.242	.449	579	....	3.3384	62.1	......	......
	197	7,000	.079	.201	.389	849	....	3.3791	62.1	......	......
	209	2,200	.081	.148	.239	1,055	....	2.2627	....	22.5	31.0
	972	17,300	.068	.137	.218	903	....	3.4950	58.0	......	......
	....	....	....	....	....	....	....	....	....	42.0	57.9
	105	863	.125	.245	.364	497	60	4.0151	74.6	......	......
	146	1,633	.051	.133	.210	830	....	3.1363	....	39.0	53.8
	1,203	13,030	.034	.081	.122	798	....	3.4339	....	39.0	53.8
	130	4,832	.075	.241	.397	....	....	3.6025	62.1	......	......
	102	1,552	.018	.232	.378	803	74	3.5274	62.1	......	......
	640	4,843	.065	.155	.238	737	....	3.8887	66.2	......	......
	672	7,482	.069	.145	.222	790	....	3.8853	66.2	......	......
	....	....	....	....	....	....	....	....	66.2	......	......
	105	1,030	.121	.223	.277	514	76	4.0022	72.65	......	......
	70	480	.109	.191	.255	407	50	4.0894	75.55	......	......
	52	385	.107	.192	.253	438	40	3.9452	73.89	......	......
	109	2,000	0.086	0.256	0.449	907	....	3.0352	53.8	......	......

tests on all propellants.
re available; therefore, it was omitted.

FLUOROCARBON PROPELLANTS

The propellants CY-10, CY-16, CY-17, and CY-18 were made using fluorocarbon binders (magnesium–Teflon–Viton). These propellants yielded better physical properties than the Nitrasol-binder formulations (Table 2).

Although the fluorocarbon propellants were easy to handle, extrude, and burn, they were not considered practical for use at this time because of the possibility of the formation of silver fluoride instead of silver iodide during burning.

PBAA PROPELLANTS

Earlier studies[3,4] with polyurethane binders indicated that non-energetic binders were feasible for use. Differential thermal analyses (DTA) and cook-off tests of Nitrasol propellants used in Cyclops I indicated a cook-off temperature of about 165°F for an 8-inch-diameter solid cylinder. Since Nitrasol must normally cure at 160°F (or more) to obtain adequate physical properties, there was always the possibility of the propellant cooking off.

As a result of these data, it was decided to investigate, extensively, the PBAA resins because they do not cook off at such a low temperature. Some data were available from several 10-pound batches of nitroplasticized PBAA "conventional" propellants, and CY-6 was formulated from these data. Calculations showed that CY-6 was slightly underoxidized and only 50% solids by volume. Another formulation, CY-12, was tried, with 66% solids by volume and a small amount of aluminum fuel incorporated to raise the energy content. No silver iodide was found in the residue products of CY-12, so other PBAA formulations were tried. CY-19 was found to be a good PBAA propellant, but it was discarded because CY-20 had better physical properties and other attributes.

Another PBAA formulation, CY-20, had an exhaust temperature of 820°K (1017°F), which is slightly below the decomposition temperature[5] of 825°K (1026°F) for silver iodide. It can be seen in Table 3 that there is too little energy present in CY-20 (for the heat losses that occur in actual rocket motors) to exhaust all the silver and silver iodide.

[3] See footnote 2, p. 1.

[4] Memorandum from Ronald F. Vetter to D. Williams, Code 4512; Reg. No. 4571-31-62, dated 26 October 1961, CONFIDENTIAL.

[5] Handbook of Chemistry and Physics, 42nd ed. Cleveland, Ohio, Chemical Rubber Publishing Co., p. 649.

TABLE 3. SILVER AND SILVER IODIDE SLAG WEIGHTS IN MOTORS AFTER STATIC FIRING

Motor no.	Propellant	Wt. of silver, g	Wt. of silver iodide, g
2 1/2-inch Alecto			
Av. of 3	CY-20	120–130	130–150
10	CY-20	140	not determined
12	CY-20	129	do.
13	CY-20	127	do.
14	CY-20	145	do.
16	CY-20	128	do.
17	CY-20	140	do.
18	CY-20	125	108
26	CY-21	125	not determined
28	CY-21	118	do.
29	CY-21	68	do.
35	CY-21	135	do.
39	CY-21	73+	do.
41	CY-21	130	do.
46	CY-21	130	do.
8-inch Cyclops II			
1	CY-19	325	295
2	CY-12	15	none
3	CY-20	2,540	2,109
4	CY-20	2,404	not determined
6	CY-20	2,358	do.
9	CY-20	1,315	do.
10	CY-20	1,140	do.
12	CY-20	2,050	1,600
14	CY-20	2,404	not determined
16	CY-21	45	none
17	CY-21	45	none
18	CY-21	45	none
19	CY-21	45	none

Investigation of a motor containing CY-20 revealed a large amount of silver and silver iodide slag remaining in the motor after firing. Since it was known that the higher flame temperatures supplied by the aluminum fuel in CY-12 and CY-19 had left less of this undesirable slag (Table 4), a formulation switch was made. A propellant was devised containing essentially the equivalent volumetric binder percentage as CY-20 (to allow the use of CY-20 grains for testing purposes) with a small amount of aluminum added. This new propellant was designated CY-21. Table 3 shows the results of tests with no measurable amount of slag present in any of the CY-21 motors.

TABLE 4. 8-INCH-DIAMETER CYCLOPS II MOTOR-FIRING SUMMARY

All motors had L-C-2 inhibitor liner and a 6 1/2-inch cruciform grain of magnesium–Teflon–Viton propellant in a modified Mk 264 pyrogen igniter with a 0.2-inch-diameter nozzle.

Motor no.	Propellant	Propellant wt., lb	Preconditioning	Heat liner	Nozzle insert	Slag wt., g		Burning time, sec	Type of test	Comments
						Ag	AgI			
1	CY-19	58	None	None	Graphite	325	295	34[a]	....	....
2	CY-12	67.4	None	One layer silicone-glass tape insulation	RPD 150	15	None	....	....	Fired with fin assembly attached & held open. 65% nozzle area increase caused by nozzle erosion. Motor pressure dropped & chuffing occurred, partially negating test.
3	CY-20	69.3	None	None	Graphite	2,540.1	2,109.2	90.4[b]	....	Motor wall bowed out because of heat & pressure but did not fail.
4	CY-20	60	2 1/4 hr at −65°F	0.02-in. RPD 40	Graphite	Not determined	Not determined	~80	40,000-ft simulated altitude vacuum ignition	....
6	CY-20	60	None	0.085-in. phenolic–asbestos cloth	Graphite	do.	do.	~78	40,000-ft simulated altitude vacuum ignition. Go–no-go	Vibration-tested, then fired.
9	CY-20	60	None	0.085-in. phenolic–asbestos cloth	Graphite	do.	do.	48[c]	Go–no-go	Vibration-tested, then fired.
10	CY-20	60	48 hr at −30°F	0.085-in. phenolic–asbestos cloth	Graphite	do.	do.	~75	....	Dropped 5 ft, then fired. Unusual pressure peak developed.
12	CY-20	60	48 hr at 70°F	0.085-in. phenolic–asbestos cloth	Graphite	do.	do.	60	....	Dropped 5 ft, then fired. High pressure peak developed.
14	CY-20	60	5 1/3 hr at −65°F	0.085-in. phenolic–asbestos cloth	Graphite	do.	do.	~88	40,000-ft simulated altitude vacuum ignition	....
16	CY-21	60	None	0.085-in. phenolic–asbestos cloth	Graphite	do.	do.	~85	Go–no-go	Vibration-tested, then fired.
17	CY-21	60	None	0.085-in. phenolic–asbestos cloth	Graphite	None	None	70[d]	40,000-ft simulated altitude vacuum ignition	Vibration-tested, then fired.
18	CY-21	60	48 hr at −65°F	0.085-in. phenolic–asbestos cloth	Graphite	None	None	....	....	Dropped 5 ft, then fired. Ignition delay at 10 sec. Pressure peak toward end of burning.
19	CY-21	60	None	0.085-in. phenolic–asbestos cloth	Graphite	Not determined	Not determined	~80	Go–no-go	Vibration-tested, then fired.

[a] Burned through.
[b] At a relatively low pressure of 97 psig.
[c] Burned well but instrumentation failed at 70 seconds.
[d] Quite high pressure peak developed and shortened burning time.

Table 5 shows the results of IBM calculations on the PBAA propellants CY-12, CY-20, and CY-21.

LEAD IODATE STUDIES

CY-9, CY-11, CY-13, and CY-14 were made to obtain some information on the incorporation of lead iodate into a propellant. Lead iodate is insoluble (in almost all known solvents) and therefore is available only in small particle sizes (obtained by precipitation from

TABLE 5. RESULTS OF IBM CALCULATIONS ON VARIOUS CY PROPELLANT FORMULATIONS

The following information is based on (1) PBAA = $C_{100}H_{125}$, with a heat of explosion of −21 cal/g and a density of 0.0395 lb/in^3; (2) $AgIO_3$, with a heat of explosion of −149 and a density of 0.2008 lb/in^3; (3) TMETN = $C_5H_9N_3O_9$, with a heat of explosion of −221 cal/g and a density of 0.0525 lb/in^3; and (4) aluminum, with a heat of explosion of 0 cal/g and a density of 0.0975 lb/in^3.

Property	Propellant				
	CY-12	CY-16	CY-20	CY-21	Special
Specific impulse (1,000→14.7), lb-sec/lb					
Frozen	119.8	127.6	114.3	119.2	123.1
Shifting	126.6	137.0	154.5	126.2	130.9
Exhaust temperature					
°K	1516	2137	820	1371	1615
°F	2269	3388	1017	2009	2448
Ratio of molar heat capacities, γ (av.)	1.2524	1.2311	1.2667	1.2621	1.2498
Thrust coefficient, C_F	1.57	1.58	1.564	1.566	1.571
Characteristic exhaust velocity, C*	2595	2790	3179.8	2593	2681
Exhaust gases, mole-%					
HI	8.88	0.07	20.51	12.68	7.47
H_2	4.48	0.01	6.24	7.81	5.62
I_2	1.01	0.09	1.50	1.05	0.62
Ag	0.02	9.41	....	....	0.08
H_2O	13.83	0.21	7.90	10.49	13.00
CO_2	18.82	22.87	31.49	15.09	14.79
I	11.50	20.51	0.08	6.18	13.06
CO	16.09	2.66	6.73	22.90	19.47
N_2	1.03	....	1.08	0.98	1.02
OH	....	0.01	....	....	....
O	....	0.01	....	....	....
HF	....	8.57	....	....	....
MgF_2	....	5.68	....	....	....
O_2	....	0.07	....	....	....
CH_4	....	....	0.51	....	....
Exhaust products (liquid or solid), mole-%					
Ag	22.38	11.36	23.60	20.97	21.67
Al_2O_3	1.96	....	....	1.85	3.20
MgF_2	....	4.91	....	....	....
MgO	....	13.56	....	....	....
C	....	....	0.35	....	....

the mother liquor of a double displacement reaction). CY-13 shows that a Nitrasol propellant with lead iodate can be extruded to yield physical properties similar to P-65, using identical ingredients with an equal amount of lead iodate replacing the silver iodate. The magnesium–Teflon–Viton formulation (fluorocarbon-based CY-14) gave the best physical properties of the few formulations tested; however, no lead iodate grains were made, and work was stopped on this material following a talk with Dr. Vincent Schaeffer of the University of Nevada, Reno, concerning cloud seeding. According to Dr. Schaeffer, tests in cold chambers indicated that lead iodide does not nucleate ice crystals to form rain drops at temperatures above −20°F. Dr. Schaeffer also stated that, in his opinion, crystal size of the iodides should be about 200 to 500 angstroms (0.20 to 0.50 micron) rather than the 0.50- to 1-micron size tried for in Cyclops I.

EXTRUSION

It was believed desirable to use extruded grains as well as cast grains for the various formulations. Table 6 shows extrusion parameters of the CY propellants and P-65, indicating which of these

TABLE 6. EXTRUSION TEST PARAMETERS

Propellant	Intermediate pressure, psi	Temperature, °F	
		Barrel	Oven
CY-1	6,600	130	130
CY-2	10,000	130	130
CY-3	5,000	130	130
CY-4	6,000	130	130
CY-5	4,700	130	130
CY-7	11,000	130	130
CY-8	10,700	130	130
CY-9	..........[a]	130	130
CY-10	10,300	225	197
CY-10 (1.2-in. rod)	10,000	150	150
CY-10 (3/32-in. rod)	20,000	225	197
Modified CY-10	16,600	225	175
CY-11[b]	....	225	197
CY-12[c]	....	130	130
CY-13	4,400	140	150
CY-14	11,000	225	175
CY-15	..........[a]	130	150
CY-16	20,000	225	175
CY-17	20,000	225	175
CY-18[b]	....	225	......
P-65	4,000	130	130

[a] No pressure.
[b] Would not extrude.
[c] Not extrusible—crumbles.

propellants can be extruded. Extrusion was believed to be a more desirable method of grain preparation, especially for the 1.2-inch Alecto.

SENSITIVITY TESTS

The electrostatic, friction, and impact test results showed no friction or electrostatic positives for any of the formulations (Table 2). The impact data seem to indicate equal or poorer sensitivity for the fluorocarbon-based and PBAA formulations than for the Nitrasol formulations. However, the impact test requires only a slight reaction (discoloration of sample) to be positive.

No PBAA samples or motors have shown any indication of detonation wave propagation. All normal drop tests were negative and in a no-fire flight test from 40,000 feet altitude the unit impacted the range shattering the entire unit and the propellant, which partially burned with ignition from an undetermined source. Several chunks of propellant were found unburned among the debris.

Gap detonation tests using the standard setup[6] from the Naval Ordnance Laboratory, White Oak, with zero cards, were negative in all tests on CY-12, CY-20, and CY-21.

DIFFERENTIAL THERMAL ANALYSES

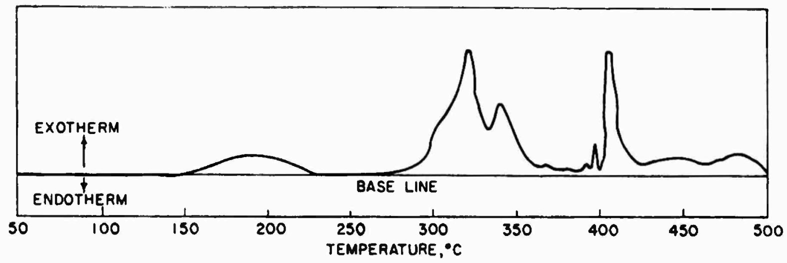
Thermograms. DTA thermograms of some of the formulations are presented in Fig. 2–4. The nitrate ester exothermic peak at approximately 180°F can be seen in many of the thermograms.

Thermal Study of CY-21. Difficulties were encountered in attempting a complete thermal analysis of CY-21, which was selected for use in the prototype units for actual use against a hurricane in the fall of 1962, under the Department of Commerce Weather Bureau Project Stormfury.

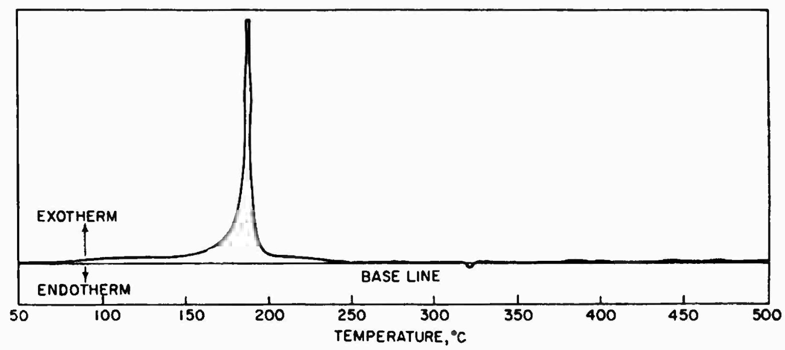
Thermal patterns of CY-21 were obtained by DTA at heating rates of 9.6, 7.8, 5.8, 3.9, and 1.9°C/min. An endothermic peak occurred at 141.1°C (av.), which did not vary with the heating rate, indicating a transition point. At the rate of 9.6°C/min, exothermic peaks occurred at 200, 261, 425, 561, and 619°C. CY-21 burned or damaged approximately 15 unshielded thermocouples during the DTA study. Usually, there is no loss of thermocouples during DTA tests.

The first peak (at about 200°C) occurred only at the two higher heating rates and not at the lower rates. No reason can be given for this at this time nor can an activation energy be determined from the two heating rates.

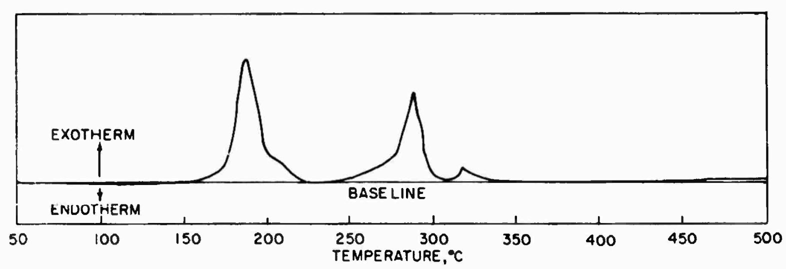
[6] Two 2-inch-diameter, 1-inch-thick tetryl pellets detonated by no. 3 blasting cap against the sample in a 5 1/2-inch-long, 1 1/2-inch-diameter steel pipe with a witness plate on top.



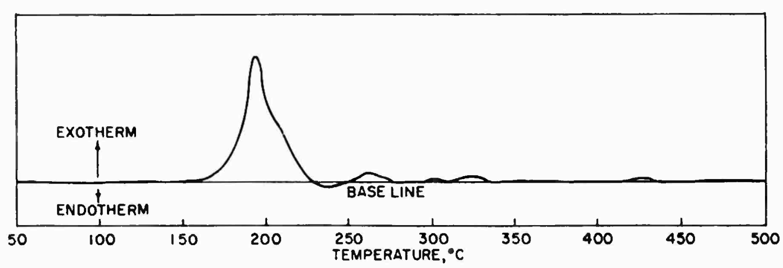
(a) CY-6.



(b) CY-7.

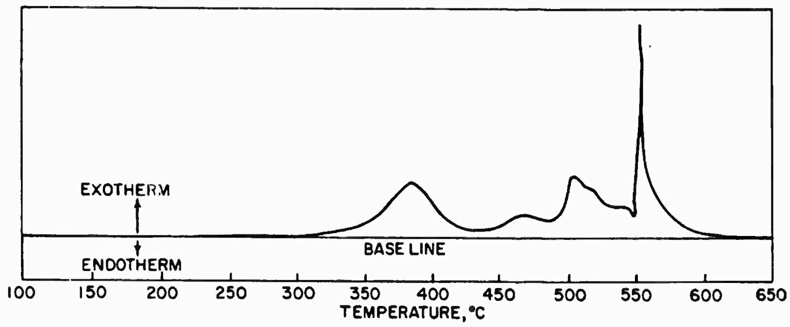


(c) CY-8.

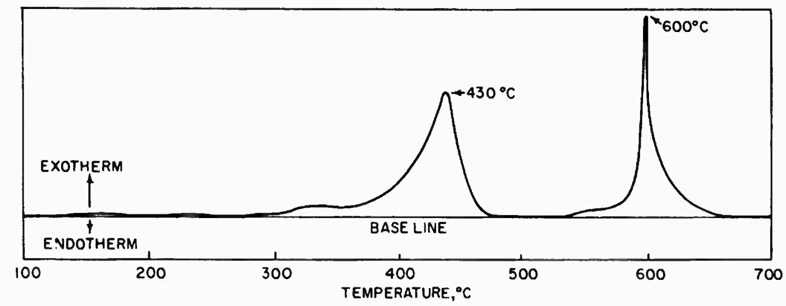


(d) CY-9.

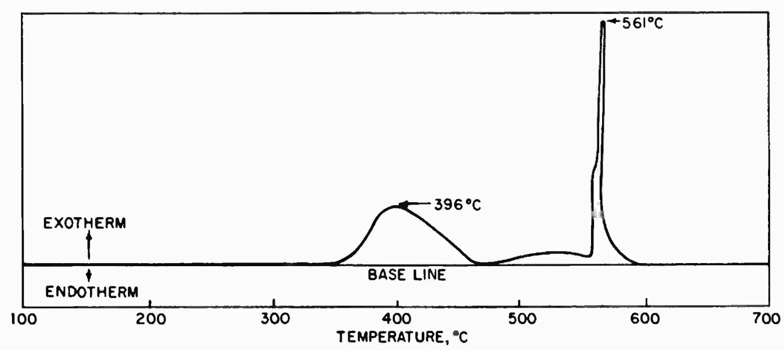
FIG. 2. DTA Thermograms at a Heating Rate of 4.83°C/min.



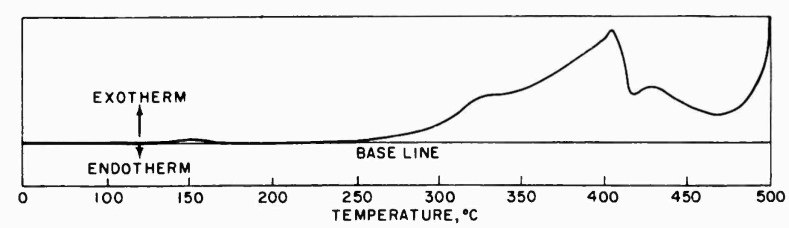
(a) Heating rate 4.80°C/min.



(b) Heating rate 19.6°C/min.

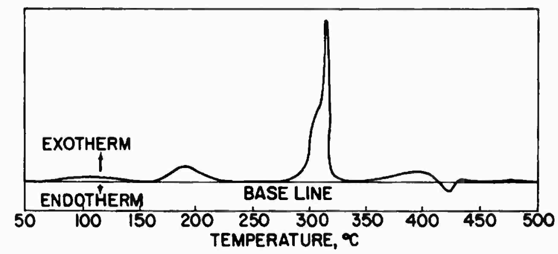


(c) Heating rate 4.81°C/min.

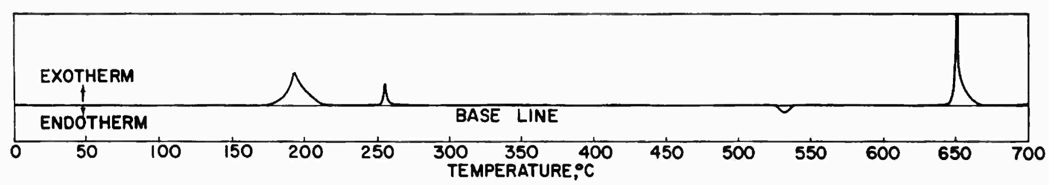


(d) Heating rate 4.84°C/min.

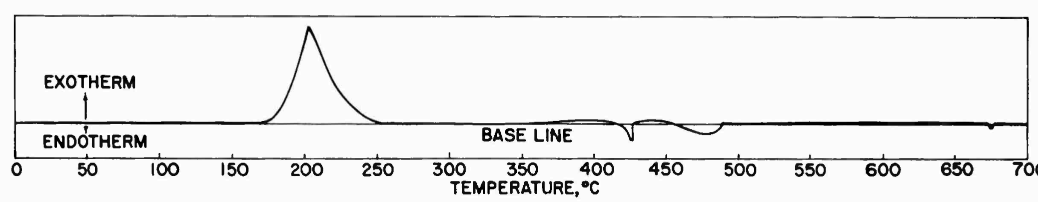
FIG. 3. DTA Thermograms of CY-10.



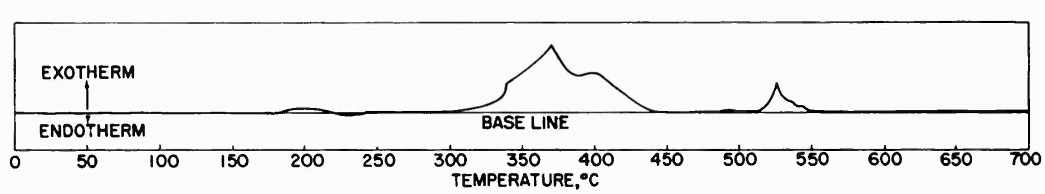
(a) CY-12 at a heating rate of 4.84°C/min.



(b) CY-13 at a heating rate of 5.76°C/min.



(c) CY-15 at a heating rate of 5.76°C/min.



(d) CY-19 at a heating rate of 5.76°C/min.

FIG. 4. DTA Thermograms of CY-12, CY-13, CY-15, and CY-19.

The second peak had a range of 321 to 361°C for a heating rate range of 1.9 to 9.6°C/min. A break in the curve occurred at the rate of 5.8°C/min. The rates 1.9, 3.9, and 5.8°C/min gave an activation energy of about 89 kcal/mole whereas the rates 5.8, 7.8, and 9.6°C/min gave an activation energy of about 32 kcal/mole. The reason for the change in the activation energy above 5.8°C/min has not been determined.

The cook-off data for two samples, 4 7/8 inches in diameter, were 13.4 and 15.3 hours at an oven temperature of 250 and 237°F, respectively. Two samples, 2 inches in diameter, at an oven temperature of 250°F, showed exothermic heat above the oven temperature. The first exotherm with the 2-inch sample lasted about 40 hours with a maximum differential temperature of 10°F for the first 11 to 13 hours. The second 2-inch-sample exotherm lasted about 100 hours with a maximum differential temperature of 10°F for the first 5 to 13 hours, after which the temperature dropped irregularly back to the oven temperature.

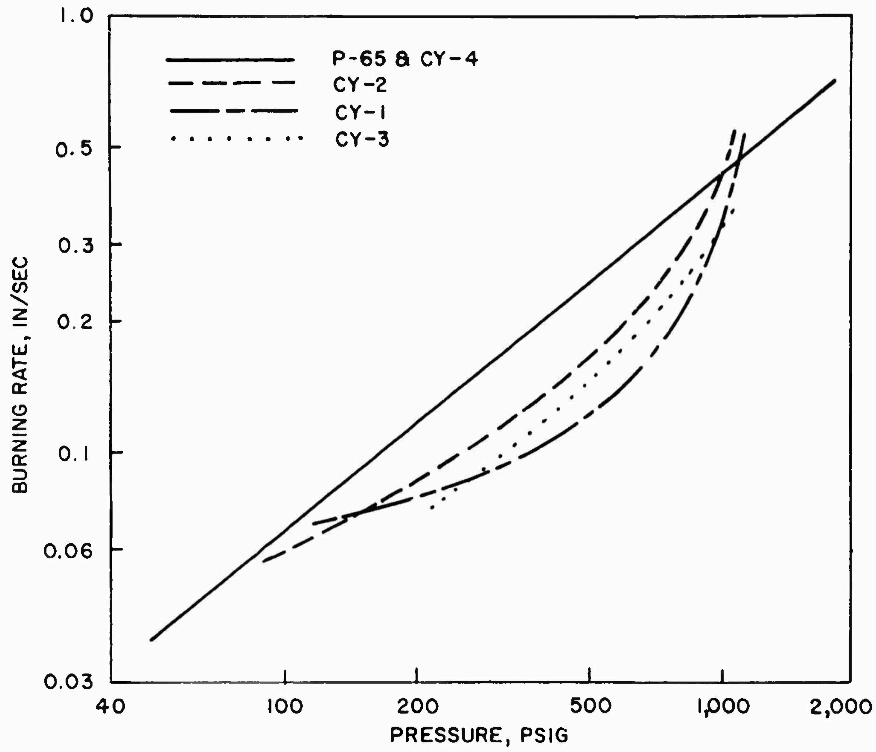
BURNING RATES

All the silver iodate formulations seem to have burning rates of approximately the same value at about 500 psig (Fig. 5). The Nitrasol formulations have pressure exponents of approximately 0.80 if the equation $r_b = cP^n$ (where r_b is the turning rate, c is the coefficient, P is the pressure, and n is the pressure exponent) is considered as valid and straight lines constructed even though they do not coincide with all the data points. The nitroplasticized PBAA formulations seem to fit the burning-rate equation well, at least in the range from 100 to 1,000 psi, with a pressure exponent of 0.35.

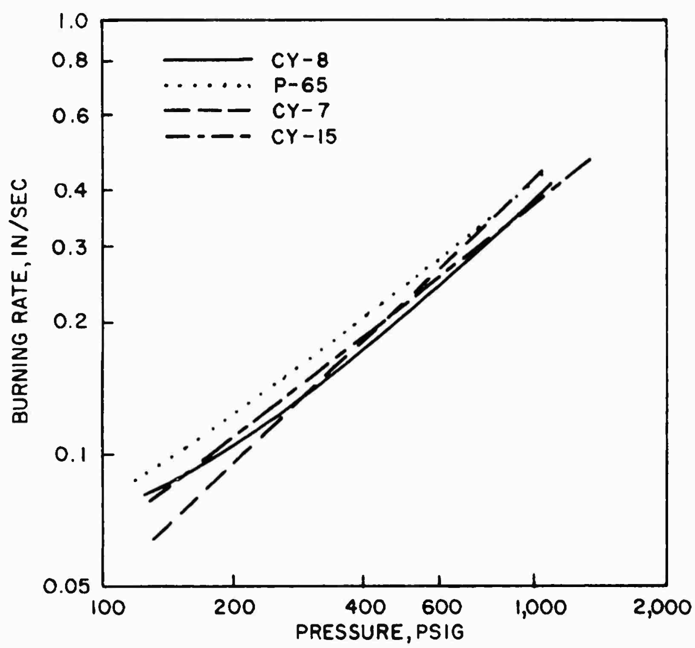
Table 7 lists the strand burning rates obtained at three temperatures in order to determine π_p and π_k, the temperature coefficients. However, the rates correspond at each pressure and show no temperature dependence. Not enough data from motor firings were generated to verify this nondependence on temperature, but indications (Fig. 6–19) are that this is the case.

TABLE 7. BURNING RATES OF CY-21

Temperature, °F	Burning rate, in/sec			
	120 psig	540 psig	1,080 psig	2,600 psig
10	0.112	....	0.252	....
79	0.107	0.192	0.253	0.378
135	0.110	....	0.246	....

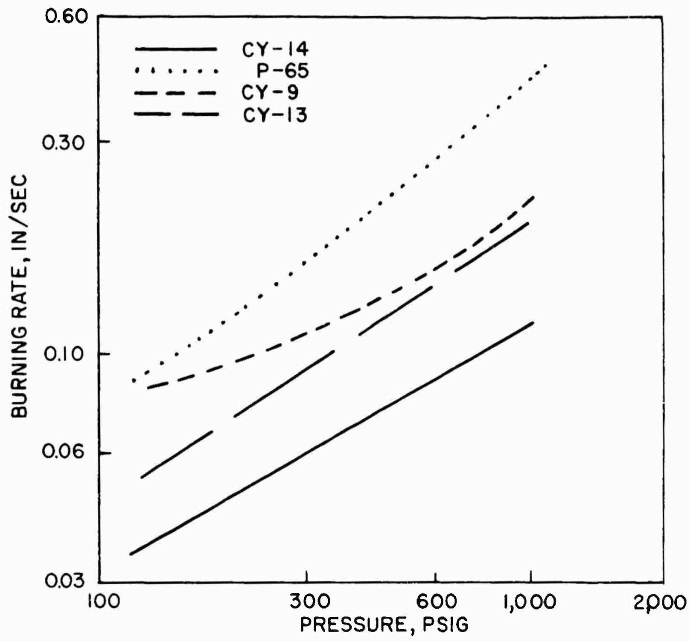


(a) P-65 compared with some of the Nitrasol formulations.

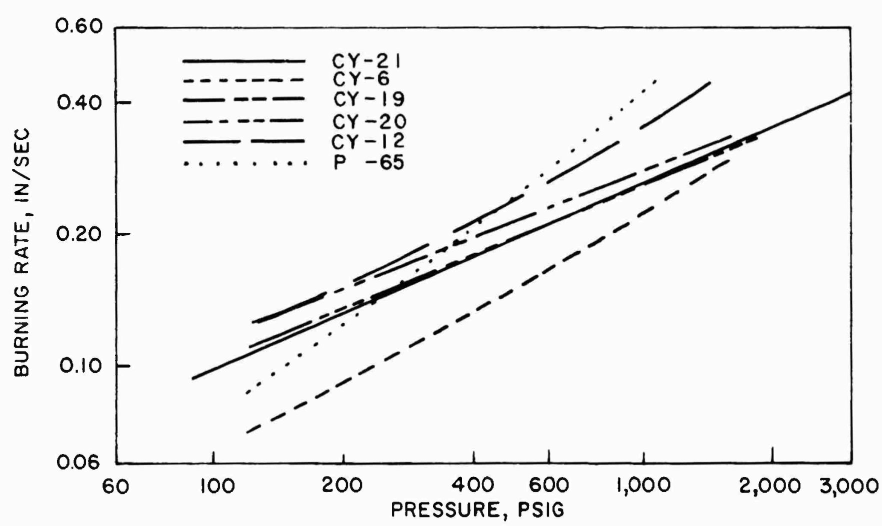


(b) P-65 compared with other Nitrasol formulations.

FIG. 5. Extruded Strand Burning Rates of Propellant Formulations.

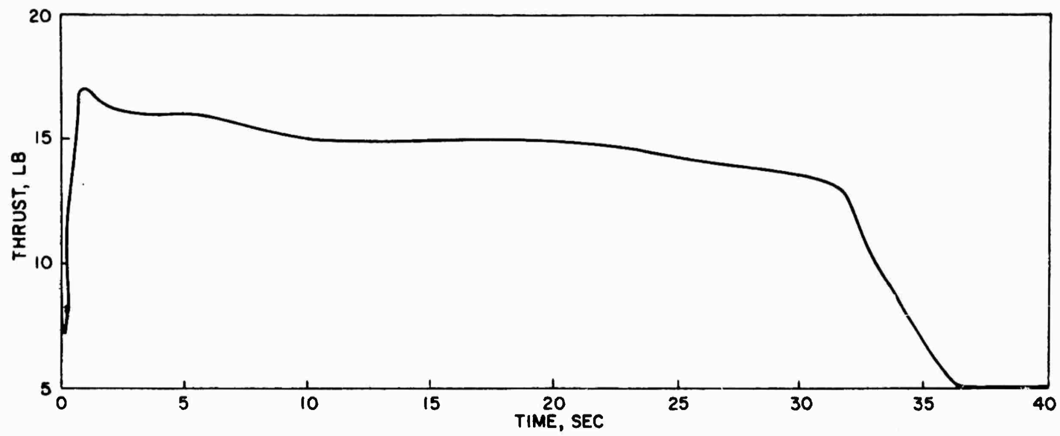


(c) P-65 compared with lead iodate formulations.

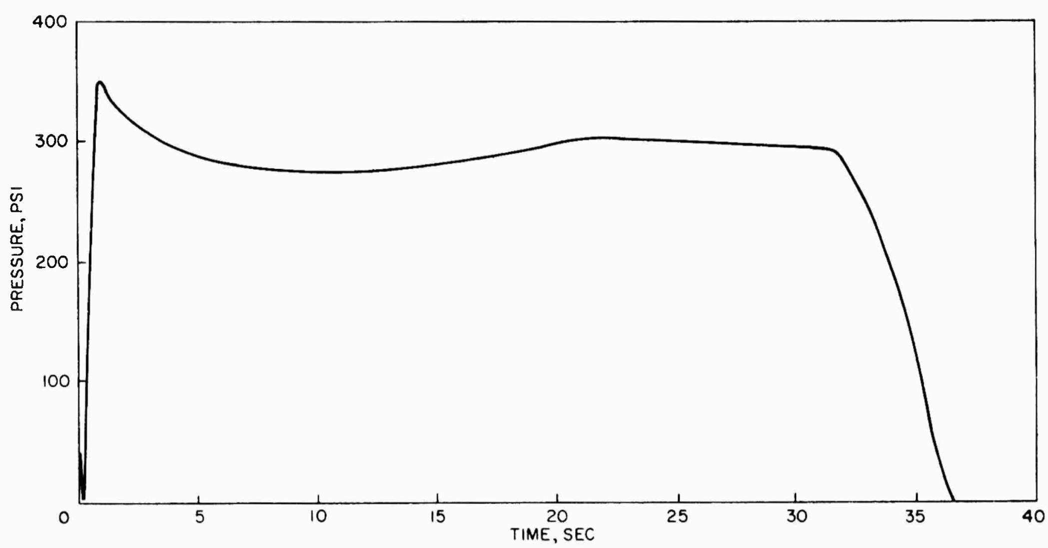


(d) P-65 compared with PBAA formulations.

FIG. 5. (Contd.)

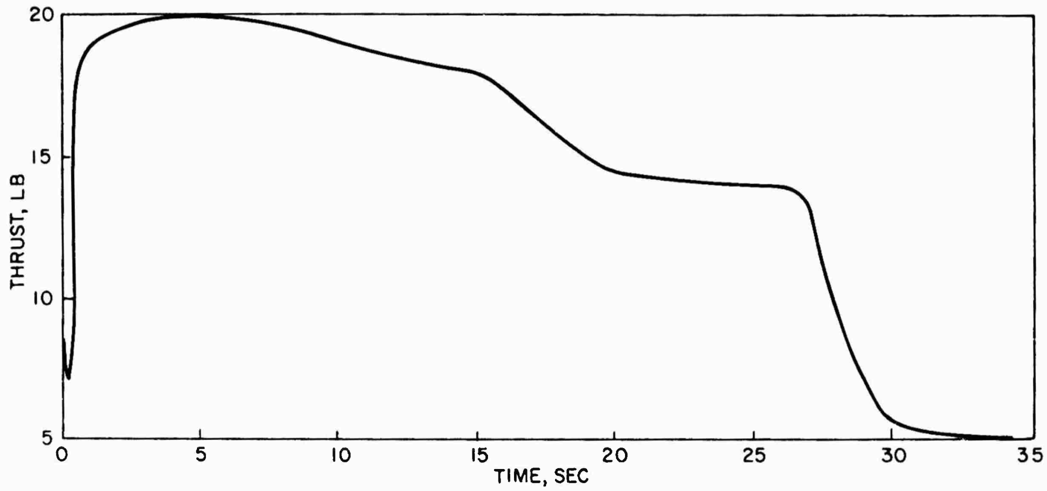


(a) Thrust data.

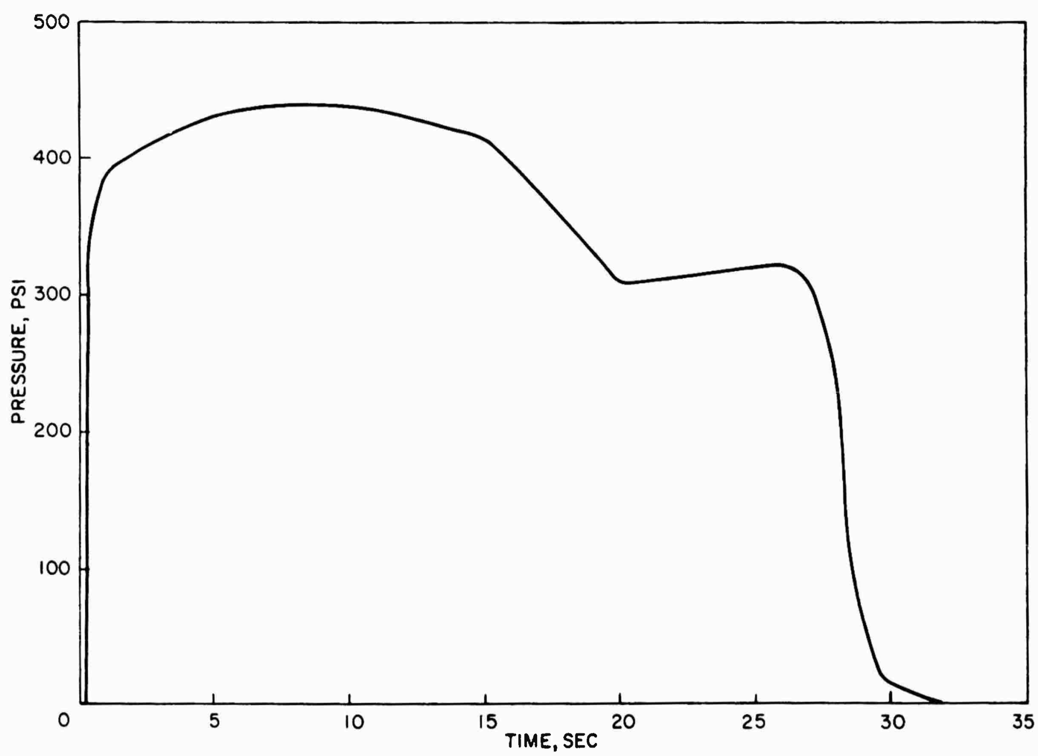


(b) Pressure data.

FIG. 6. CY-20 Static-Fired in 2 1/2-Inch Alecto Motor No. 10 at Ambient Conditions.

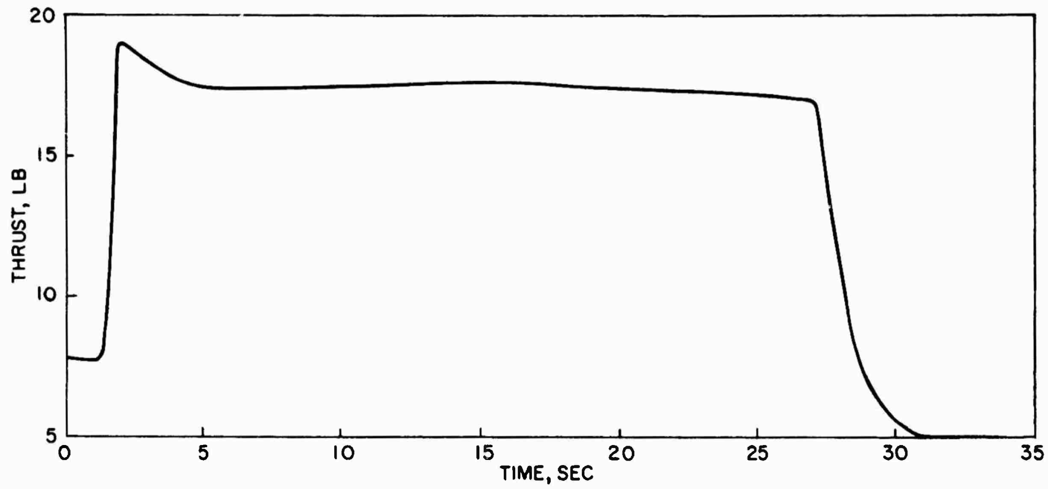


(a) Thrust data.

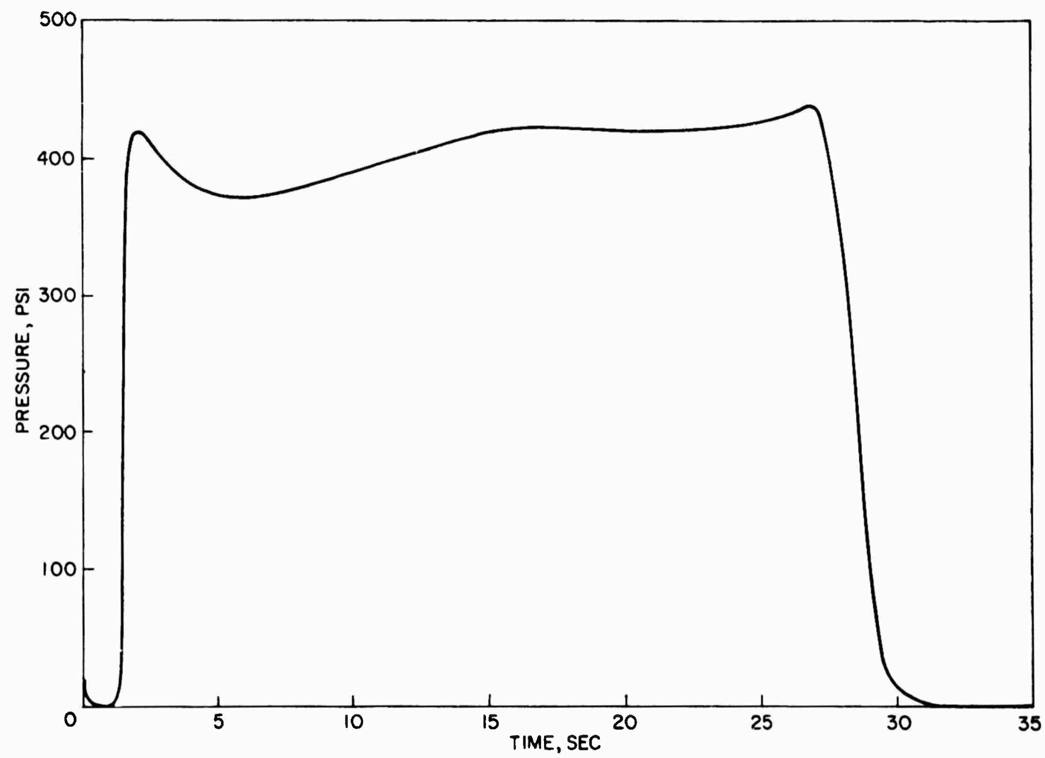


(b) Pressure data.

FIG. 7. CY-20 Static-Fired in 2 1/2-Inch Alecto Motor No. 11 at Ambient Conditions.

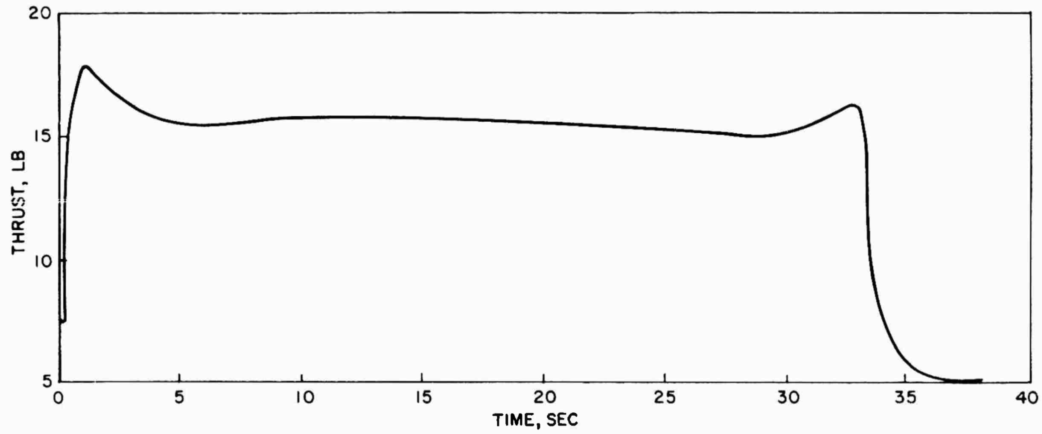


(a) Thrust data.

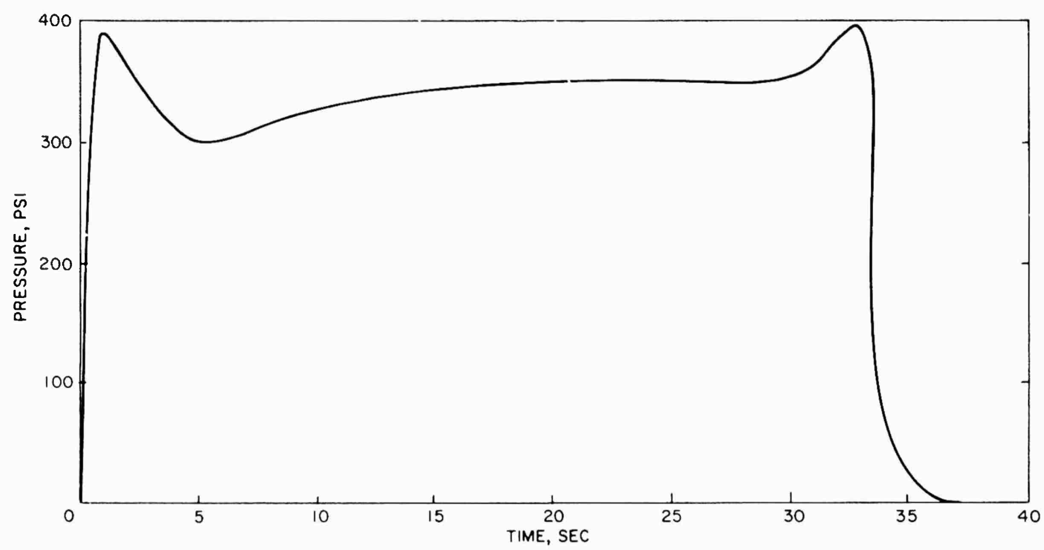


(b) Pressure data.

FIG. 8. CY-20 Static-Fired in 2 1/2-Inch Alecto Motor No. 12 at Ambient Conditions.

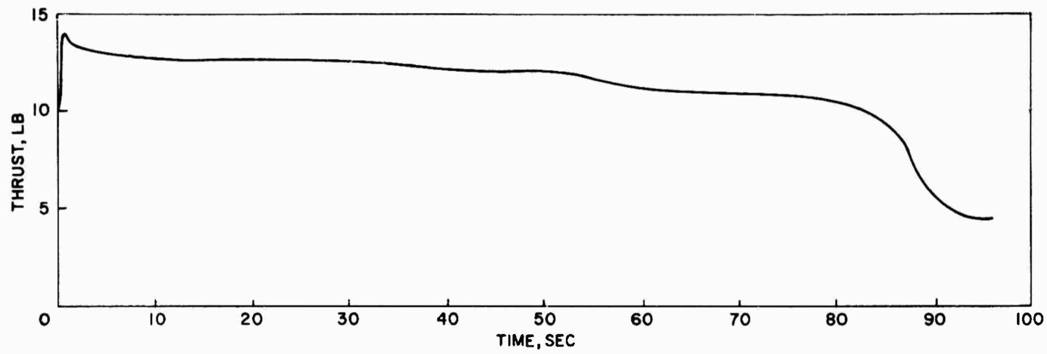


(a) Thrust data.

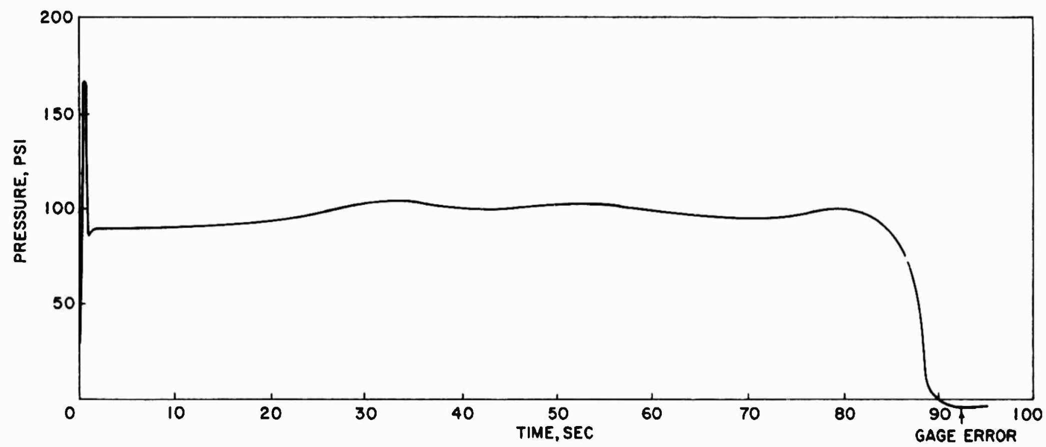


(b) Pressure data.

FIG. 9. CY-21 Static-Fired in a 2 1/2-Inch Alecto Under Ambient Conditions (70°F).

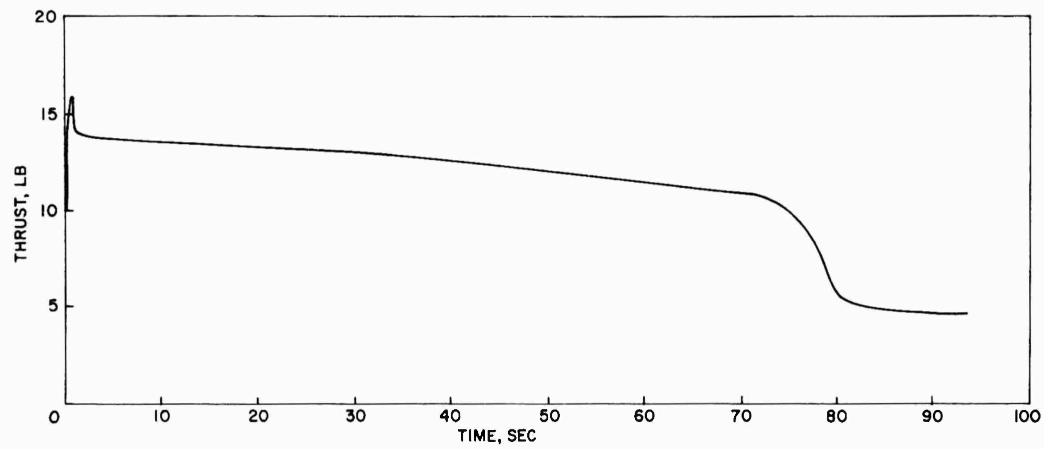


(a) Thrust data.

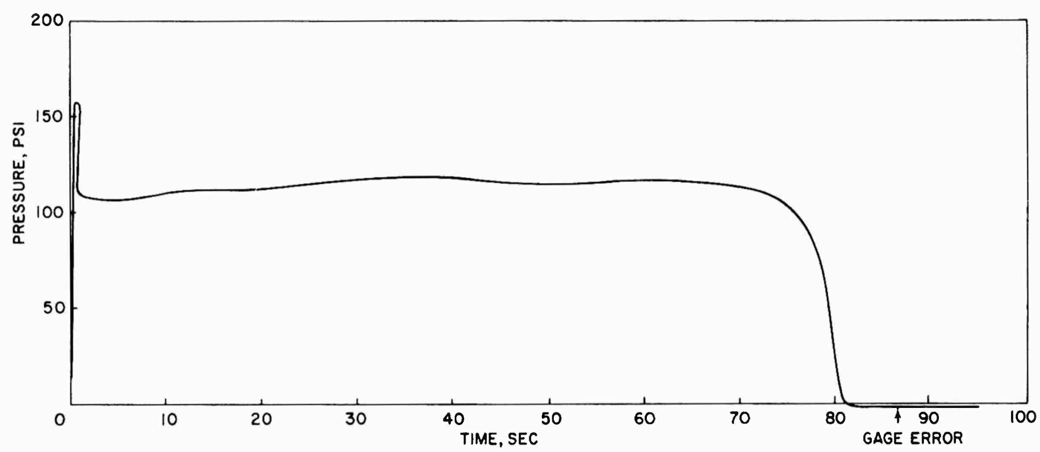


(b) Pressure data.

FIG. 10. CY-20 Static-Fired in 8-Inch Cyclops II Motor No. 14 After Preconditioning at $-65^{\circ}F$ for 5 1/2 Hours.

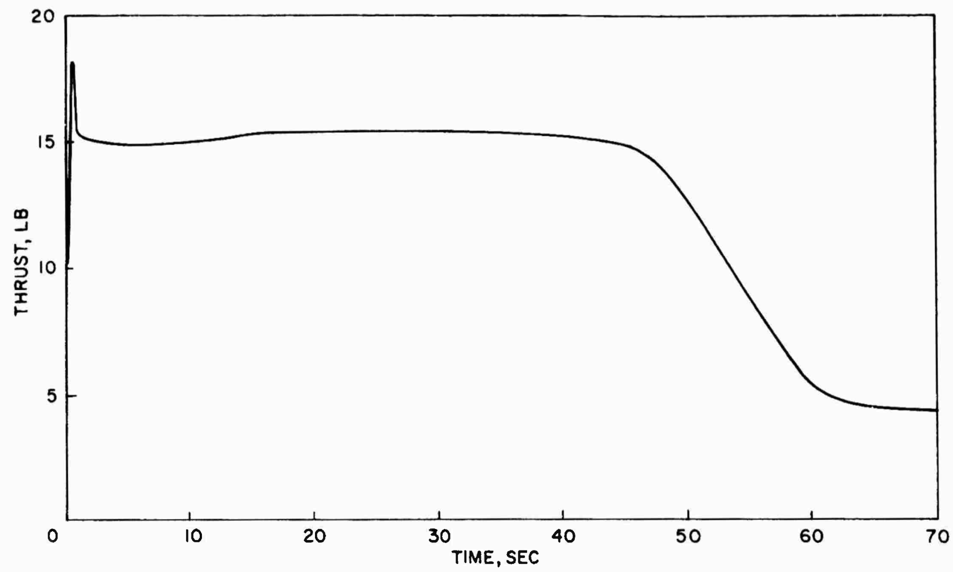


(a) Thrust data.

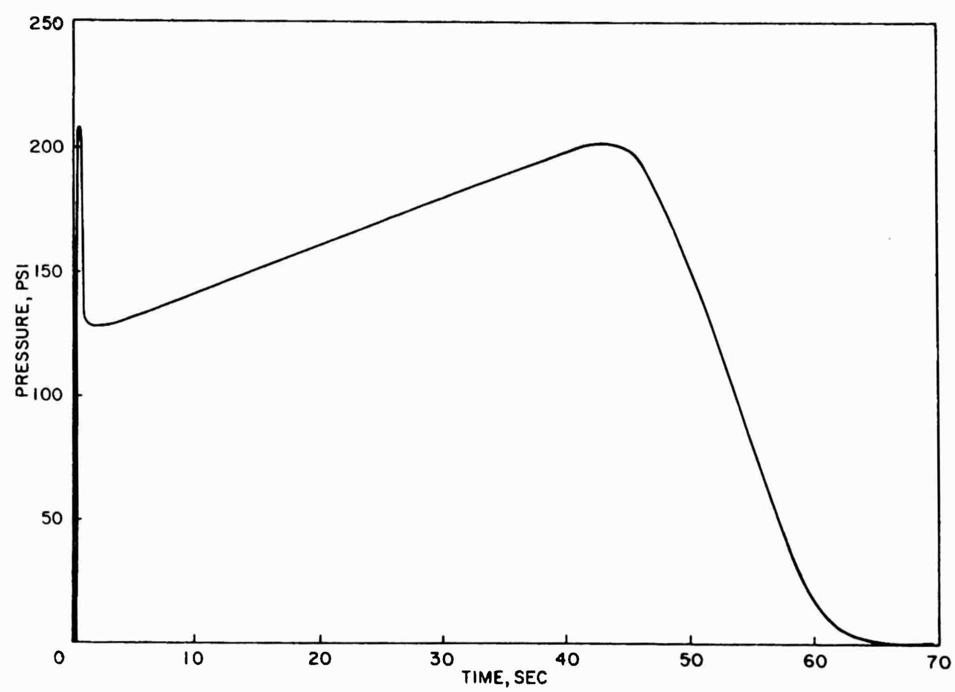


(b) Pressure data.

FIG. 11. CY-20 Static-Fired in 8-Inch Cyclops II Motor No. 4 After Preconditioning at −65°F for 2 1/4 Hours.

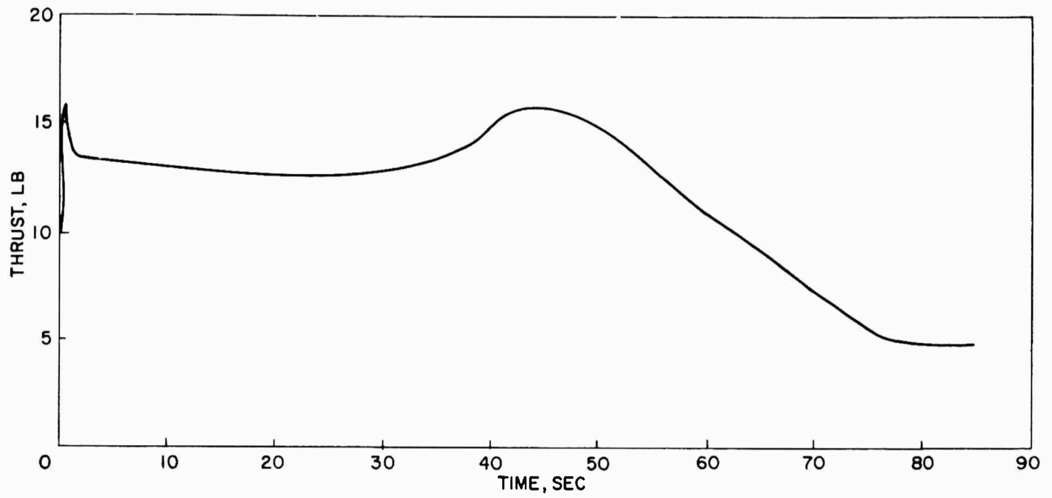


(a) Thrust data.

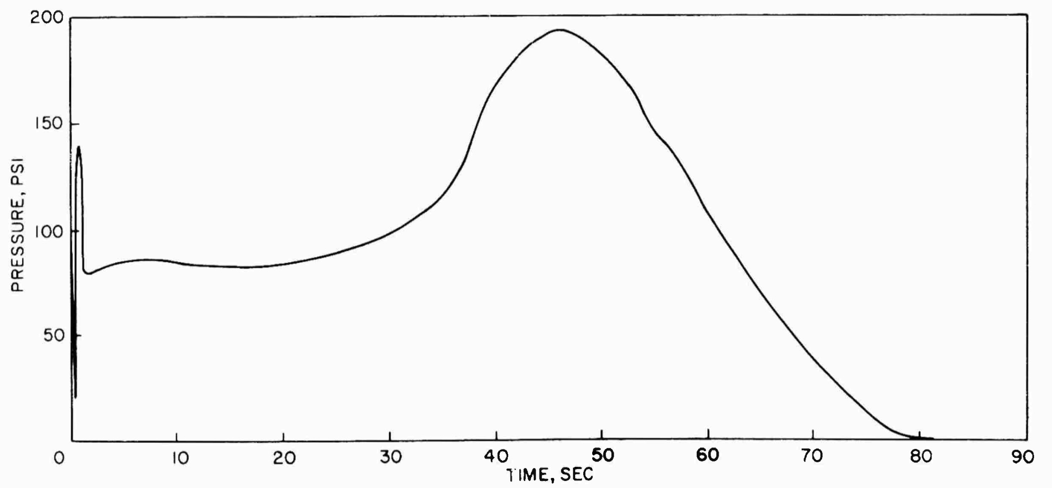


(b) Pressure data.

FIG. 12. CY-20 Static-Fired in 8-Inch Cyclops II Motor No. 12 After Preconditioning at 70°F for 48 Hours and Subjection to a 5-Foot Drop Test.

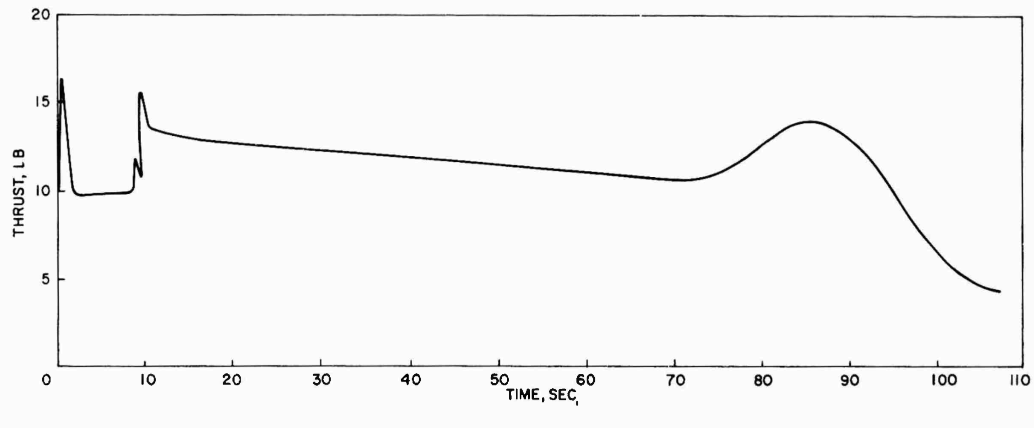


(a) Thrust data.

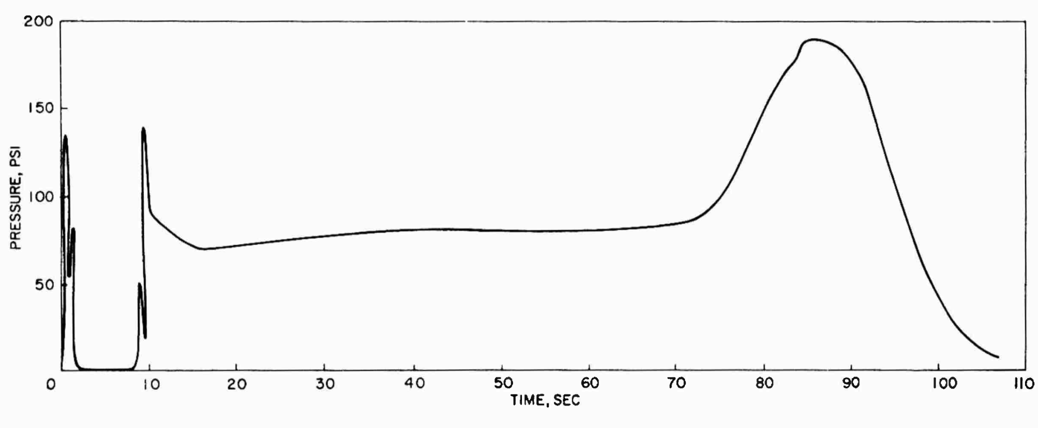


(b) Pressure data.

FIG. 13. CY-20 Static-Fired in 8-Inch Cyclops II Motor No. 10 After Preconditioning at $-30^{\circ}F$ for 48 Hours and Subjection to a 5-Foot Drop Test.

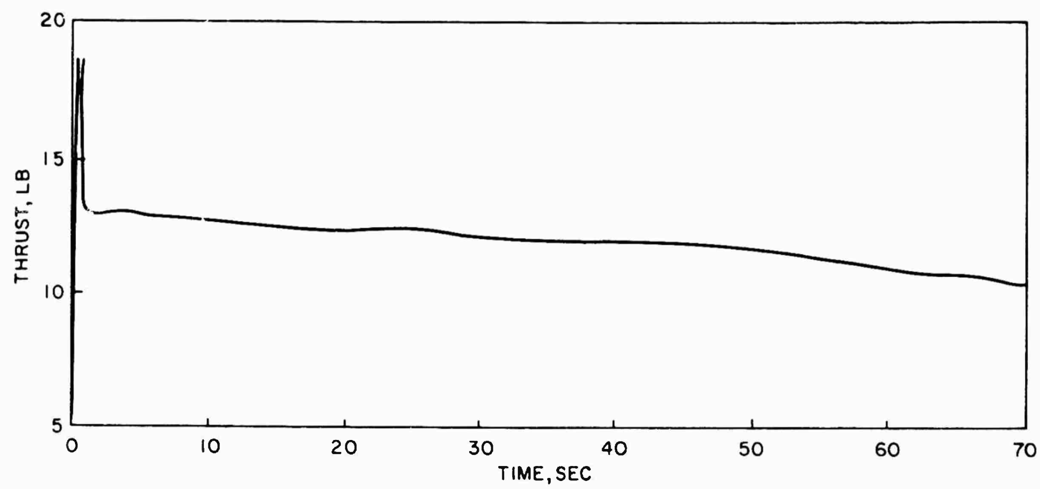


(a) Thrust data.

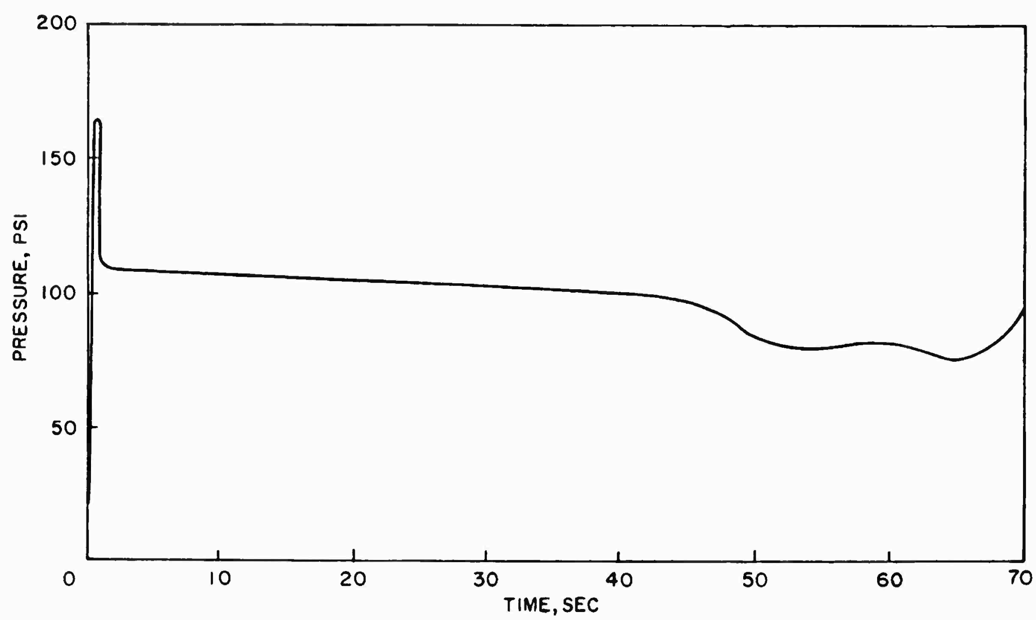


(b) Pressure data.

FIG. 14. CY-21 Static-Fired in 8-Inch Cyclops II Motor No. 18 After Preconditioning at $-65^{o}F$ for 48 Hours and Subjection to a 5-Foot Drop Test.

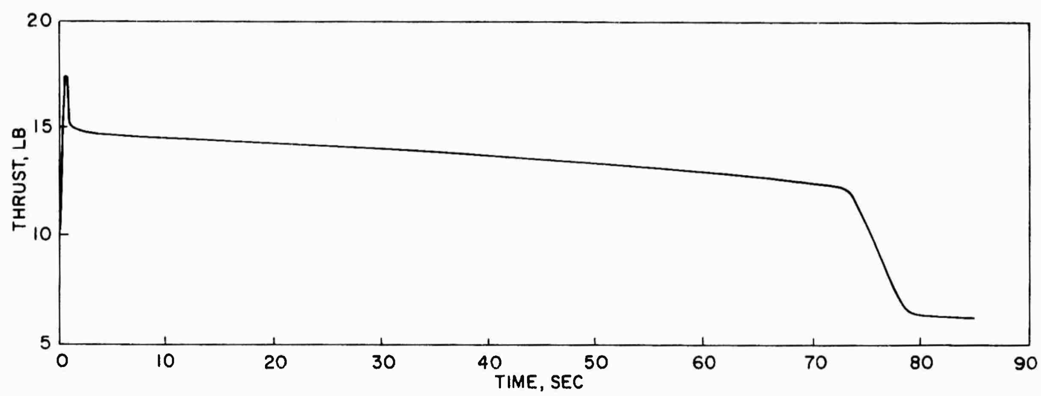


(a) Thrust data.

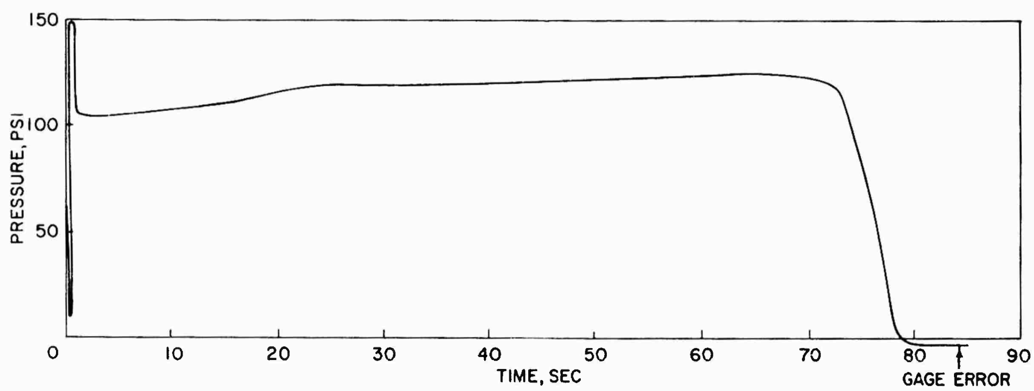


(b) Pressure data.

FIG. 15. CY-21 Static-Fired in 8-Inch Cyclops Motor No. 17 at Vacuum Ignition at a 40,000-Foot Simulated Altitude After a Vibration Test.

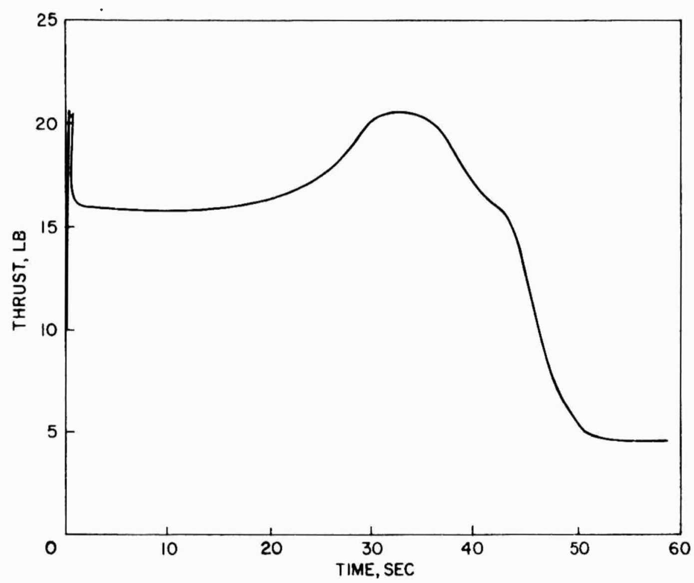


(a) Thrust data.

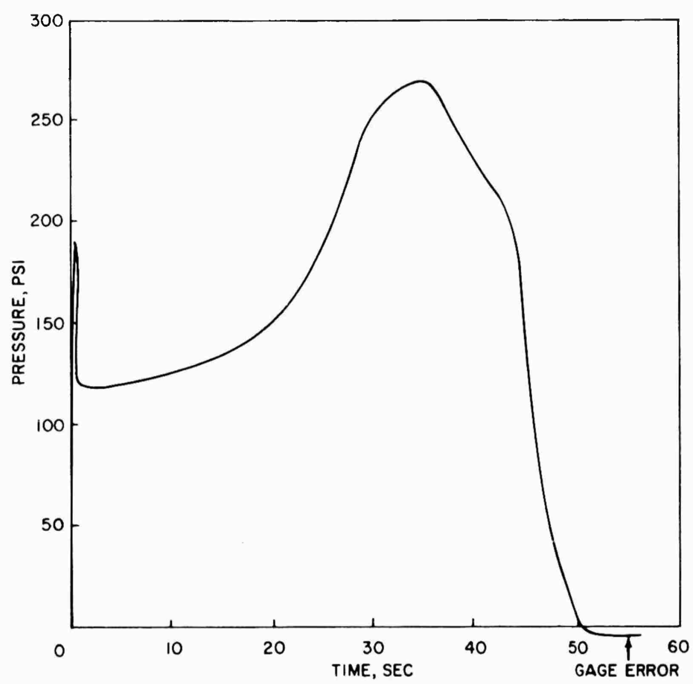


(b) Pressure data.

FIG. 16. CY-20 Static-Fired in 8-Inch Cyclops II Motor No. 6 at Vacuum Ignition at a 40,000-Foot Simulated Altitude After a Vibration Test.

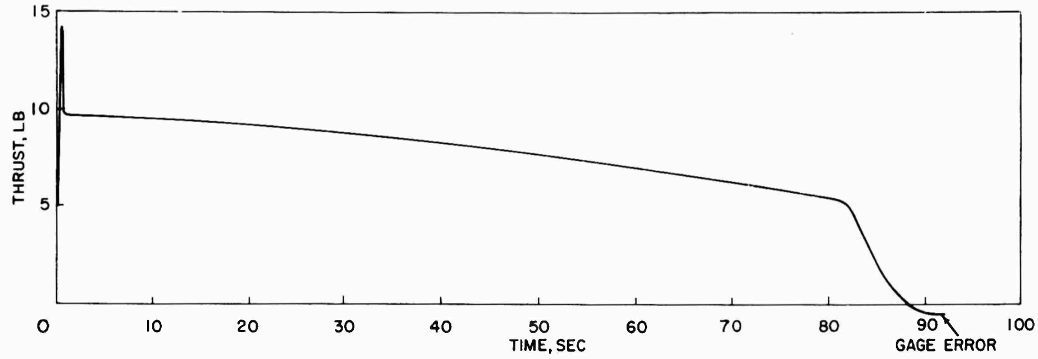


(a) Thrust data.

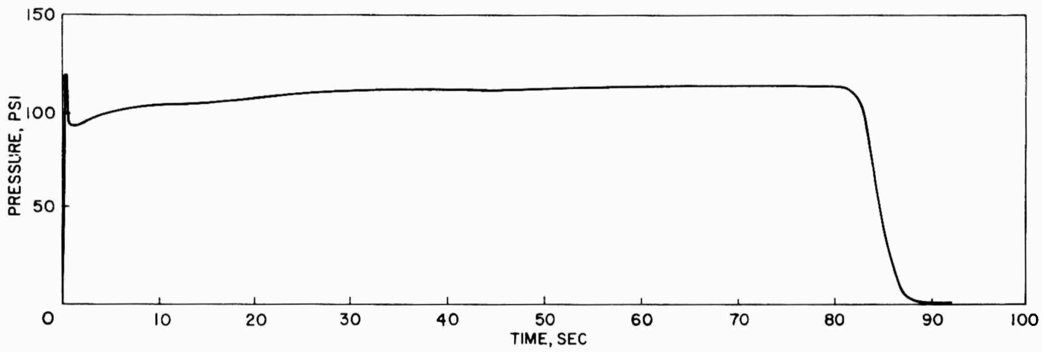


(b) Pressure data.

FIG. 17. CY-20 Static-Fired in 8-Inch Cyclops II Motor No. 9 at Ambient Conditions After a Vibration Test.

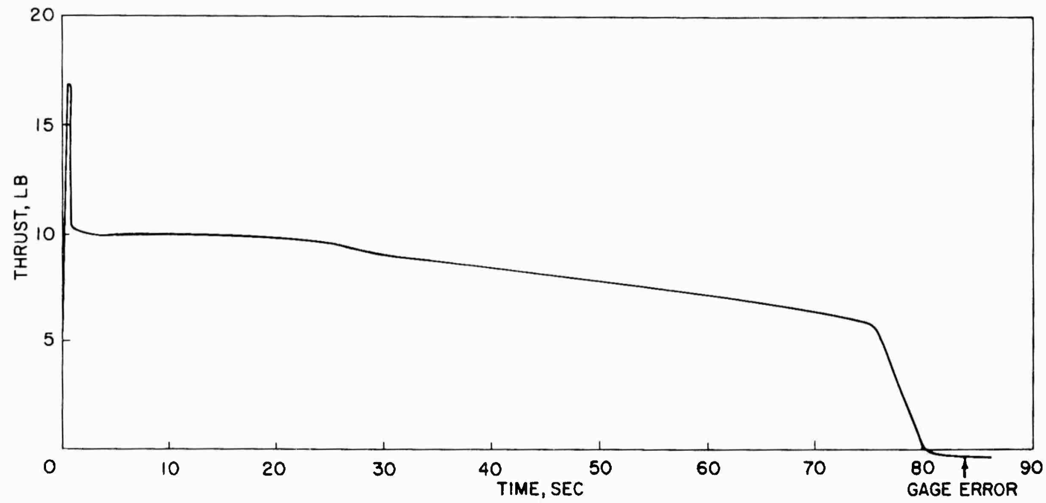


(a) Thrust data.

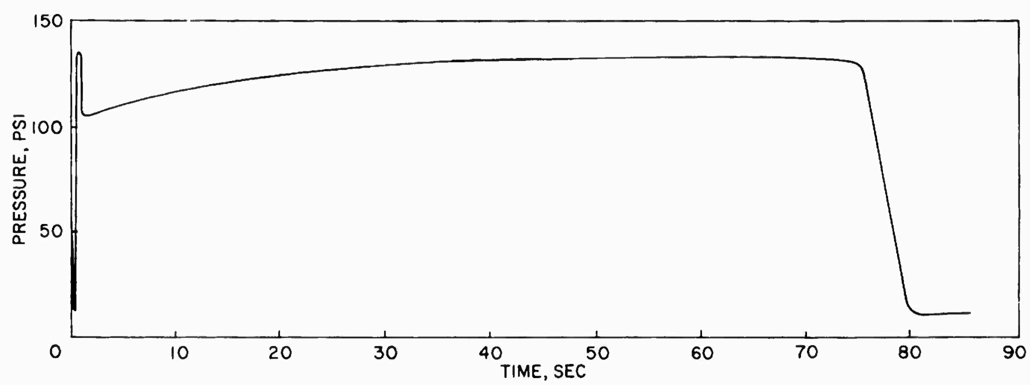


(b) Pressure data.

FIG. 18. CY-21 Static-Fired in 8-Inch Cyclops II Motor No. 16 at Ambient Conditions After a Vibration Test.



(a) Thrust data.



(b) Pressure data.

FIG. 19. CY-21 Static-Fired in 8-Inch Cyclops II Motor No. 19 at Ambient Conditions After a Vibration Test.

1.2-INCH-DIAMETER ALECTO

PROPELLANT SELECTION

Since the Alecto motor was to contain a 1.2-inch-diameter grain 15.6 inches long, extrusion was considered the most desirable propellant processing method. Several grains were prepared.

The material used in the Alecto tests came from a 100-pound batch of modified CY-10 (see Table 1). The modified formulation contained Teflon 7 instead of the Teflon 6 that was used in the original formulation. (Teflon 7 was readily available, and Teflon 6 was in short supply.) The modified CY-10 was extruded through a long, round die (with a slightly tapered entrance) on the 3-inch vertical press. The extrusion rate was about 30 in/min maximum at 10,000-psi ram pressure. Thirty-five grains about 18 inches long were obtained.

INHIBITING SYSTEM

A single coat of Stanley Primer 40X415 covered with a material to keep hot gas from direct contact seemed a sufficient inhibiting system for the magnesium–Teflon–Viton (fluorocarbon) propellant system, as had been shown in previous work at NOTS. Six motors were static-fired (Fig. 20–22). The results of the firings are presented in Table 8, with the inhibiting and potting compounds used. Another conclusion from these static tests (later verified by Cyclops II firings) was that RPD 150 (phenolic–asbestos molding compound) does not perform well as a nozzle throat because excessive erosion occurs.

TABLE 8. EVALUATION OF INHIBITING SYSTEM OF 1.2-INCH ALECTO

Inhibitor potting for liner sleeve	Potting compound into motor tube	Results
Epoxy (Epon 815 and Epocast 951 hardener)	Epoxy	Grain not "wetted" well. Pressure blowup (not inhibited).
RTV C-328 Viton cement	Epoxy	One unit fired. Pressure blowup. Nozzle ejected as above (see Fig. 22).
Stanley Primer 40 x 415, then epoxy into sleeve	Epoxy at head end only	Inhibitor good but pressure dropped during firing because of erosion of RPD 150 nozzle material. (See slag formed in Fig. 21.)
Stanley Primer, then SD-723 polyurethane into sleeve	Epoxy at head end only	Good inhibiting but slag formed, burning time too long, and stainless steel tube became red hot.
Stanley Primer wash coat only....	Grain and sleeve potted with epoxy at head end only	"Instant" overpressures ejected the nozzle plate.

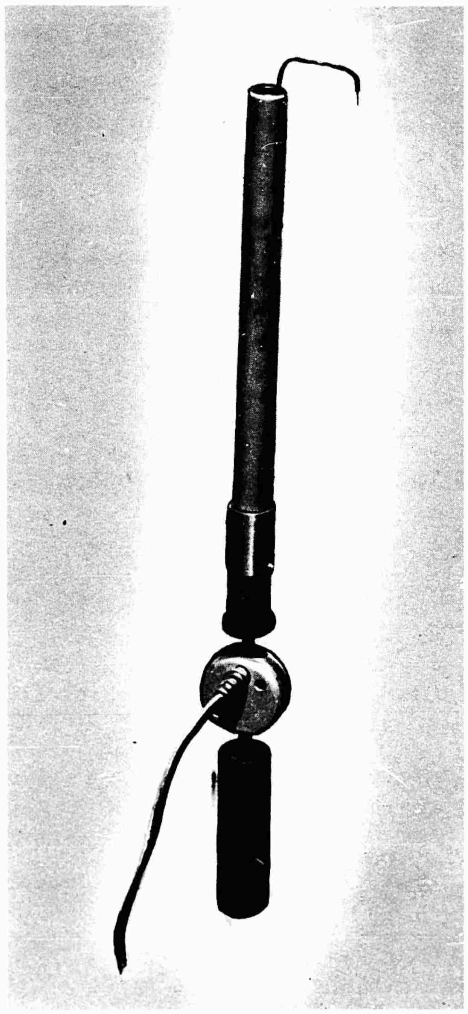


FIG. 20. 1.2-Inch Alecto in Static-Firing Stand.

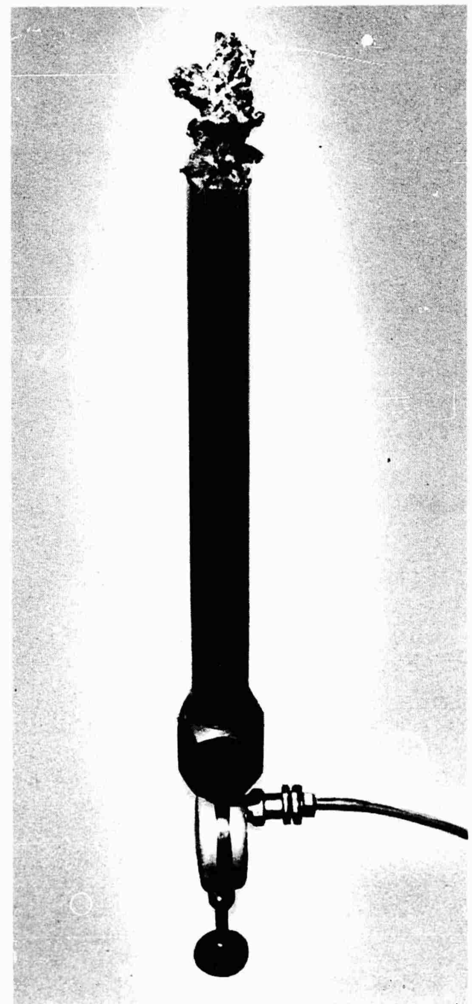


FIG. 21. Slag Buildup Above Nozzle of 1.2-Inch Alecto.

IGNITION

Ignition of the 1.2-inch Alecto was accomplished by potting a Mk 39A pyrogen squib into the RPD 150 nozzle plate using filled epoxy as a sealer.

DELIVERY PACKAGE

The 1.2-inch Alecto unit was made of stainless steel tubing containing a Kraft paper-phenolic liner, crimped head, and nozzle closures (Fig. 23). The crimping was accomplished by using a swivel

FIG. 22. 1.2-Inch Alecto After a Test Firing That Resulted in a Pressure Rupture Because of Inhibitor Failure.

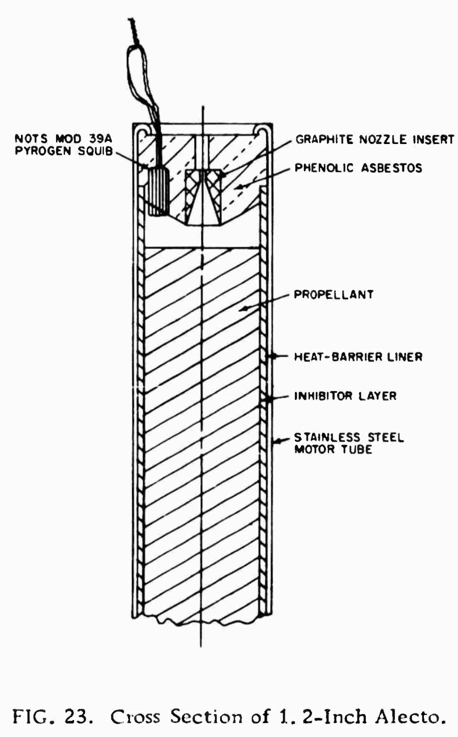


FIG. 23. Cross Section of 1.2-Inch Alecto.

ball bearing as a roller for a lathe. Approximately 10 sets of parts for these 1.2-inch-diameter 16-inch-long units were available by 3 July 1962. Several problems were found during static testing, and no further parts were made because a 2 1/2-inch-diameter unit proved to be more practical.

It should be noted that both Alecto units are end burners—the 1.2-inch grain was approximately 15 1/2 inches long and the 2 1/2-inch grain approximately 6 inches long. Burning times are different for these two grains as are the silver iodide distribution zones. The 1.2-inch unit is retarded by a ribbon parachute with the thrust directed upward, and the 2 1/2-inch unit is a free-fall device with the motor accelerated downward. No desired burning times or predicted trajectorics were obtained; therefore, the nozzle was designed to yield approximately a 400-psig motor pressure.

2 1/2-INCH-DIAMETER ALECTO

PROPELLANT SELECTION

Both casting and extrusion were considered practical for the 2 1/2-inch Alecto grain. As there were a number of modified CY-10 grains remaining from the 1.2-inch Alecto testing, these grains were to be re-extruded for use in the 2 1/2-inch Alecto. The grains were chopped into short pieces and extruded through a 2 1/2-inch-diameter round die on the 12-inch press. At the conclusion of this extruding, while the hydraulic cutter was operating to cut the second 40-inch-long grain, a fire, followed by an explosion, occurred. The grain already in the receiving tram and the newly cut grain were lost during the fire, which burned in the tram and at a few scattered points around the room (from chunks of propellant being hurled about). Investigations have not yet uncovered a definite cause for the ignition.

It was discovered that a PBAA system was better for the 2 1/2-inch Alecto. The PBAA propellants do not extrude well (see Tables 2 and 6), so a casting was employed. CY-20 and CY-21 were used, with CY-21 as the final choice in the delivered units.

INHIBITING SYSTEM

Two 2 1/2-inch Alectos were lined with L-C-3, a new liner formulation consisting of 50% boric acid and 50% L-C-2 inhibitor liner (Table 9). The boric acid was added to give heat ablative qualities to the inhibitor liner. However, the material failed to cure and was replaced with the regular L-C-2 formulation, which was case-bonded directly to the steel motor tube.

Tensile pull tests of L-C-2 liner–PBAA propellant bond averaged 65-psi tension and yielded a 90 to 100% cohesion (0 to 10% adhesion) in the propellant near the interface.

TABLE 9. L-C-2 CASE-BONDED-INHIBITOR LINER FORMULATION

Ingredient	%
Butarez CTL II[a]	66.14
MAPO[b]	3.86
CB–Thermax[c]	30.00
Total	100.00

[a] The quantity must be adjusted to the quantity of MAPO so that two equivalents of imine are available per equivalent of carboxyl.
[b] Tris[1-(2-methyl)aziridinyl]phosphine oxide.
[c] Thermatomic-grade thermax carbon black.

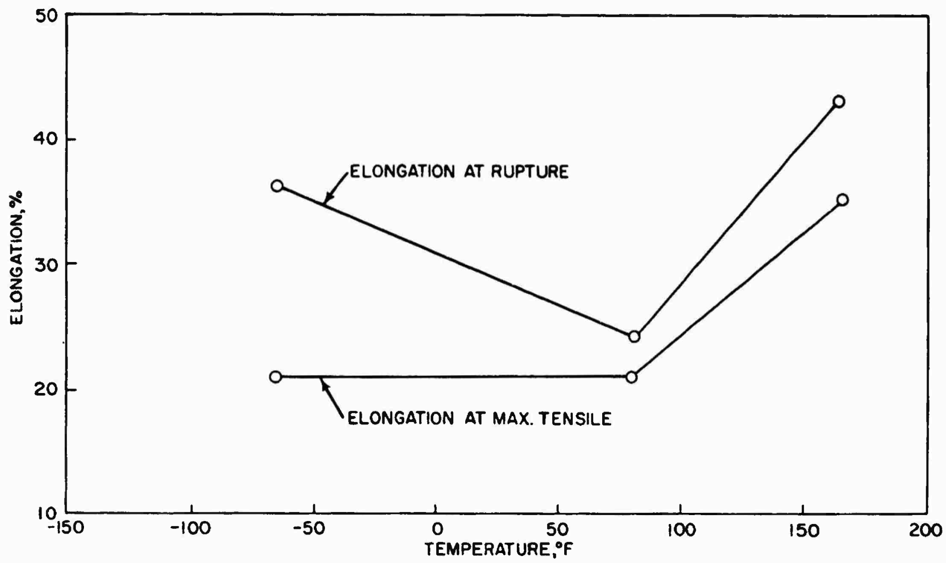
Similar results were obtained with CY-20 and CY-21 propellant cast onto L-C-2 liner that was itself cast onto steel fixtures and cured at 150°F for 24 hours. The propellant in these tests generally yielded at lower tensile stresses, so that the break occurred at 50 to 60 psi. Figure 24 shows tensile data for CY-21.

IGNITION

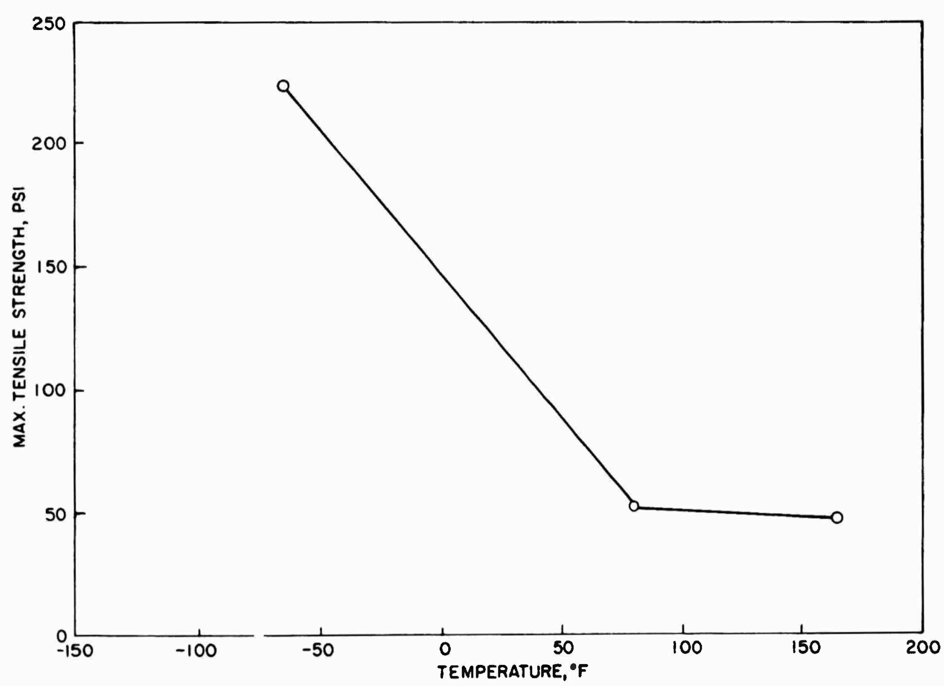
Crimping of the 2 1/2-inch Alecto to install the nozzle plate was accomplished as for the 1.2-inch Alecto. Static tests were conducted using a pyrogen squib mounted in a bolt that was attached at the firing area. The ignition system was also tested but no instrumentation could be used, since the M123 canister totally enclosed the motor and the ejection charge firing yields too high a thrust level compared with the motor thrust to allow use of a thrust gage. Therefore, it was strictly a go–no-go test conducted in a reverse manner, in that the motor was held stationary and the M123 canister ejected.

The two motors lined with L-C-2 were static-fired to obtain ballistic data and action times. An extruded length of magnesium–Teflon flare mixture, with a 0.100-inch outside diameter and a 0.030-inch inside diameter, threaded with nichrome wire, was used as an igniter and functioned well on one unit, but the nichrome wire burned too fast on the second test and did not ignite the flare mixture. On the first test, a burn-through occurred after 15 seconds, indicating a need for a heat liner. The average pressure until burn-through was about 380 psig. These motors each contained about 5 pounds of CY-20 propellant. The nozzles were of ATJ graphite with a throat diameter of 0.166 inch, calculated to produce a motor pressure of about 400 psig, mounted with a tapered wedge seal into the steel nozzle plate and bonded with unfilled epoxy resin (Fig. 25).

Two 7/8-inch-diameter by 0.100-inch-thick magnesium–Teflon disks were coated on one face with Stanley Primer 40X415 and then adhered to the center of the grain surfaces of motors no. 13 and 26 with epoxy resin. Neither the CY-20 in motor no. 13 nor the CY-21 in



(a) Elongation.



(b) Tensile Strength.

FIG. 24. Tensile Data for CY-21.

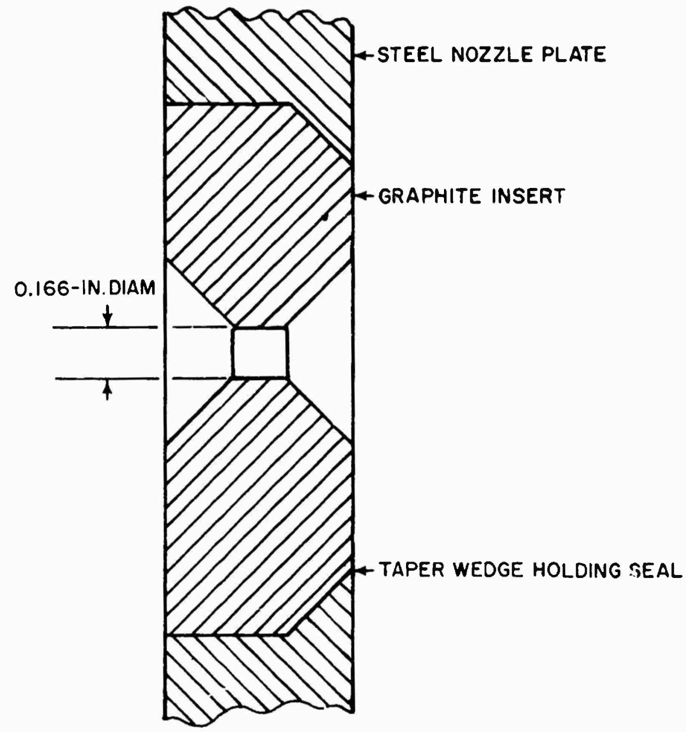


FIG. 25. Schematic of Nozzle Insert on 2 1/2-Inch Alecto.

motor no. 26 ignited when the canister ejection charge of boron-potassium nitrate pellets burned. However, both units functioned satisfactorily when an additional train of magnesium-Teflon "spaghetti" was inserted to extend from the extreme after end through the nozzle throat to the disk. Because of the shape of the combined disk and spaghetti, this igniter was called a "tophat."

One of the CY-21 grains was ignited using a pyrogen squib to obtain pressure-thrust-time data (Fig. 6-19). A CY-16 extruded grain coated with Stanley Primer 40X415 and bonded with epoxy resin to a graphite cloth-phenolic heat barrier was ignited similarly and resulted in a high-rate pressure failure after an ignition delay and burning at 400 psig for 200 ms.

Ignition problems were encountered when new pressed magnesium-Teflon tophats were used in the nozzle (Fig. 26). Seven firing attempts resulted in five delayed ignitions of 6.5, 6.5, 6.5, 7.4, and 8.6 seconds and two complete failures. Addition of a 0.050-inch-thick strip of magnesium-Teflon through the orifice yielded 9.4 seconds delay in two tests. Since the original tophats were machined, new units were made by machining, and three test firings resulted in (1) a 1/2-second delay, (2) no ignition, and (3) a 3 1/2-second delay.

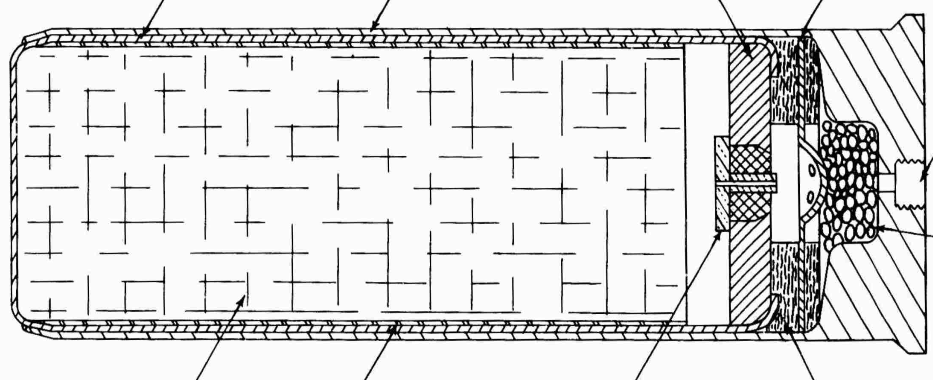


FIG. 26. Cross Section of 2 1/2-Inch Alecto.

A group of motors was next prepared using several ignition materials in slurry or lacquer form painted onto the tophat igniter trains. Particulars and results are presented in Table 10. Since the Alclo lacquer "D" (Table 11) gave the best results, seven more units were prepared using this material and then static-fired. All ignited, and ignition delay to full pressure varied from 1/2 to 2 1/2 seconds.

One further test was conducted using Alclo lacquer "D" over the entire exposed surface of the tophat, and on a nickel-sized area on the center of the grain surface. Twenty of these units were air-dropped over the range. Seventeen were seen to ignite by the pilot and the others were lost in the clouds.

HEAT LINERS

Several tests were made to evaluate a number of available heat-liner materials in the 2 1/2-inch Alecto motor. Results of these tests and two canister ignition tests are shown in Table 12.

Motor no. 55 was used to evaluate a heat liner wound of phenolic-asbestos felt (Taylor Fibre Co. AAA grade). The liner thickness was approximately 0.030 inch and it performed satisfactorily with CY-21 propellant.

DROP-TEST UNITS

Three units were returned after 5-foot drop tests, and they were static-fired following another X-ray. The X-ray showed no change in grain condition. Motor no. 14 (CY-20) was fired at 70°F, no. 29 (CY-21) was fired at −30°F, and no. 28 (CY-21) was fired at −65°F. All three tests were successful (the CY-21 propellant burned about 35 seconds).

VIBRATION-TEST UNITS

Four units each of CY-20 and CY-21 propellant were put through aircraft vibration tests in two axis orientations at −30°F and ambient temperatures. These units were again X-rayed and four units, taken at random, were static-fired successfully at ambient conditions. The remaining four units underwent transportation vibration testing and were then fired successfully.

TABLE 10. IGNITER PAINT TEST RESULTS

Motor no.	Coating	Portion coated	Time, sec.	
			Delay	Burning
1	PbO_2–Zr–Mg–PMVT	top & bottom	4	44
2	PbO_2–Zr–Mg–PMVT	bottom	3	44.5
3	100 parts ground AP to 10 parts PNC in nitromethane	top & bottom	......[a]	......[a]
4	100 parts ground AP to 10 parts PNC in nitromethane	bottom	......[a]	......[a]
5	100 parts ground AP to 10 parts PNC in nitromethane	top & bottom of tophat	......	......
6	100 parts ground AP to 10 parts PNC in nitromethane	bottom of tophat	13	46
7	Alclo lacquer (methylene chloride)	top & bottom	2	45
8	Alclo lacquer	bottom	1.5	45
9	Kel-F igniter paint	top & bottom	......	......
10	Kel-F igniter paint	bottom	4	43
11	Mg–Teflon flare mix and Eastman 910	top & bottom	......	......
12	Mg–Teflon flare mix and Eastman 910	bottom	5	45

[a] No ignition.

TABLE 11. ALCLO LACQUER "D" FORMULATION

Ingredient	%
Aluminum (flaked)	25.0
Potassium perchlorate	73.0
Polymethyl vinyltetrazole	2.0
Solvent (methylene chloride)	......[a]

[a] The polymethyl vinyltetrazole is dissolved in methylene chloride, and the other ingredients are added with stirring. Further stirring and methylene chloride addition are necessary during application to maintain uniformity and desired coating thickness.

TABLE 12. EVALUATION OF HEAT-LINER MATERIALS IN THE 2 1/2-INCH ALECTO

Motor no.	Test particulars	Test results
6	Canister-ignition test using 70 boron–potassium nitrate pellets in place of photoflash ejector charge. Flame vented into nozzle via perforated disk. CY-20 grain surface coated with $B-KNO_3$ igniter lacquer.	Ignited after long delay.
7	Canister-ignition test (as in motor no. 6), but no lacquer.	Did not ignite.
9	0.085-inch-thick 50% Ironsides 101 impregnated asbestos cloth heat liner (10P225 asbestos with 50 ± 5% Ironsides resin, U. S. Polymeric Chemicals, Inc.).	No test because of igniter discontinuity.
24	LS 10127 heat liner installed (phenolic–asbestos paper).	Motor failure—pressure blowup.
25	LS 10108 heat liner installed.	No test—igniter discontinuity.

DELIVERY PACKAGE

M123 photoflash canisters, already in existence, were utilized as the delivery package for the 2 1/2-inch Alecto (Fig. 25). However, the nozzle-throat diameter was increased to 13/64 inch to increase the action time to 42 seconds. A second benefit from the enlarged nozzle throat was that no appreciable amount of silver or silver iodide slag was found in any of the motors with the longer burning time.

On 7 September 1962, 20 units were flight-dropped. All ignited and burned for about 35 seconds while falling 10,000 feet.

FINAL DESIGN

The first shipment of new motor cases of final design was received on 7 September 1962. These motor cases were drawn tubes and not welded at the head end as were all previous units. All these motors were cast with CY-21 propellant to within 1 inch of the uncrimped tube end using free casting from a slightly pressurized container. The propellant was mixed in a standard vertical mixer (Fig. 27) with a final vacuum cycle and cast through a bottom casting valve into the lined motor tubes. The grain weights were about 4 pounds each.

Final assembly was completed, and the 390 units remaining after testing were shipped to the magazines on 28 September 1962 for subsequent use against a hurricane.

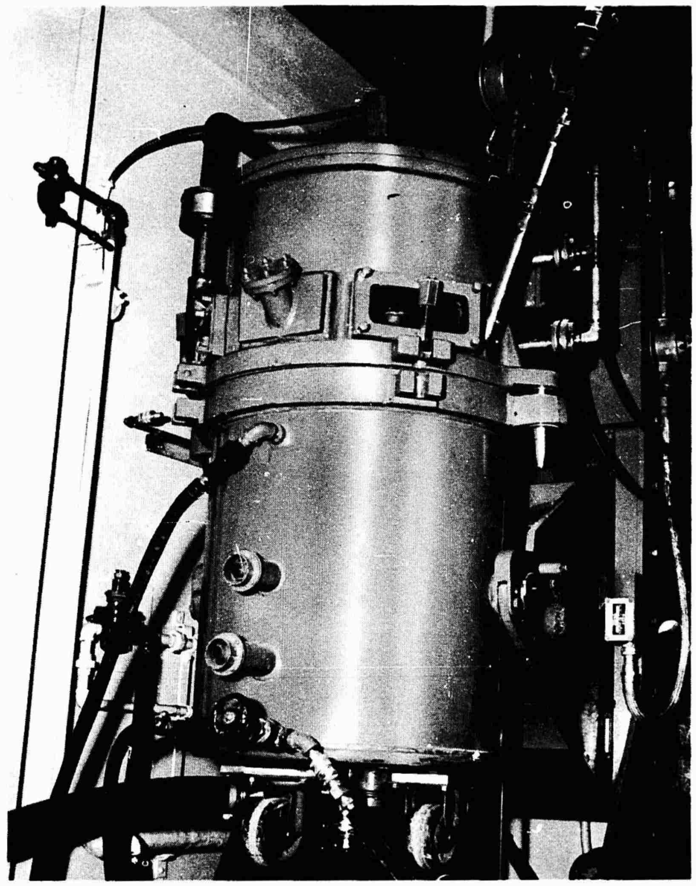


FIG. 27. 25-Gallon Vertical Propellant Mixer.

8-INCH-DIAMETER CYCLOPS II

PROPELLANT SELECTION

When a change in program outlook was made and units were to be ready by the hurricane season of 1962 instead of 1963, a design and formulation freeze was necessary to meet the delivery date. Since CY-20 was the latest formulation, had been fired successfully in a motor, and contained the highest percentage of silver iodate, this propellant was arbitrarily selected for use until it was discovered that there was too much silver and silver iodide slag left in the motor. A design change was made at this time, to CY-21 (see p. 2, Propellant Formulation Studies).

A cast end-burning grain about 8 inches in diameter was believed optimum.

PROPELLANT PROCESSING

All of the vertical mixers at NOTS were utilized to process the nitroplasticized PBAA CY formulations. Batch sizes varied from 16 to 1,600 pounds. These were mixed at one-third to one-half volumetric loads in the 1-, 5-, 25-, and 150-gallon mixers, since these low volumetric loadings yielded generally larger batch weights than normal because of the very high densities of the CY formulations.

The mixing procedure involved degassing the liquids for 10 minutes in the mix can, followed by incremental or continuous additions of solids and wetting. The polyimine catalyst was then added to the batch and final mixing accomplished under vacuum. The final cycle time varied from a minimum of 20 minutes to a maximum of 30 minutes, depending upon mixer operating speed and planetary design. (The double-planetary revolving paddles require less mixing time than the st[illegible]ary sun-revolving single-planetary paddles.) The propellants w[illegible]st from a pressurized pot through a bottom casting valve.

The propellants for all the Cyclops units were cured at 135°F. The cure apparently was not complete even after 160 hours, but the physical properties were sufficient after 70 hours.

Shore A-2 durometer hardness as a function of time for a number of batches can be seen in Fig. 28. It should be remembered that these are single-batch measurements and the connecting lines are merely indicative of the gradual curve that would be obtained from accurate continuous measurement.

HEAT-LINER SYSTEM

The same heat-liner system was used on all motors loaded after no. 4, which contained asbestos felt installed with epoxy. This material performed satisfactorily but allowed the motor tube to get much hotter than the 0.085-inch-thick Ironsides 101 phenolic-resin-impregnated asbestos cloth used in motors subsequent to no. 4. Motor no. 2 had a single layer of silicone-impregnated glass cloth that performed satisfactorily, but this motor did not perform normally (because of severe nozzle erosion) and the silicone tape was somewhat difficult to install. As a result, the phenolic–asbestos cloth liner was selected for use. (Motors 1 and 3 had no heat liner at all.)

The selected heat liner was cut to dimensions of 10 3/16 inches by 24 7/8 inches using scissors and razor knives, then coated on one side with Epon 815 epoxy resin containing 10% Epocast 951 hardener, and inserted into the motor tube (with head end installed) with a lap of approximately 1 inch. Then, the assembly was placed in a 250°F oven for a maximum of 2 1/2 hours. L-C-2 inhibitor liner was then applied with a brush to obtain over-all coverage of the heat liner and motor head end to a thickness of approximately 0.005 inch. A curing time of 16 hours minimum at 150°F was used for this liner.

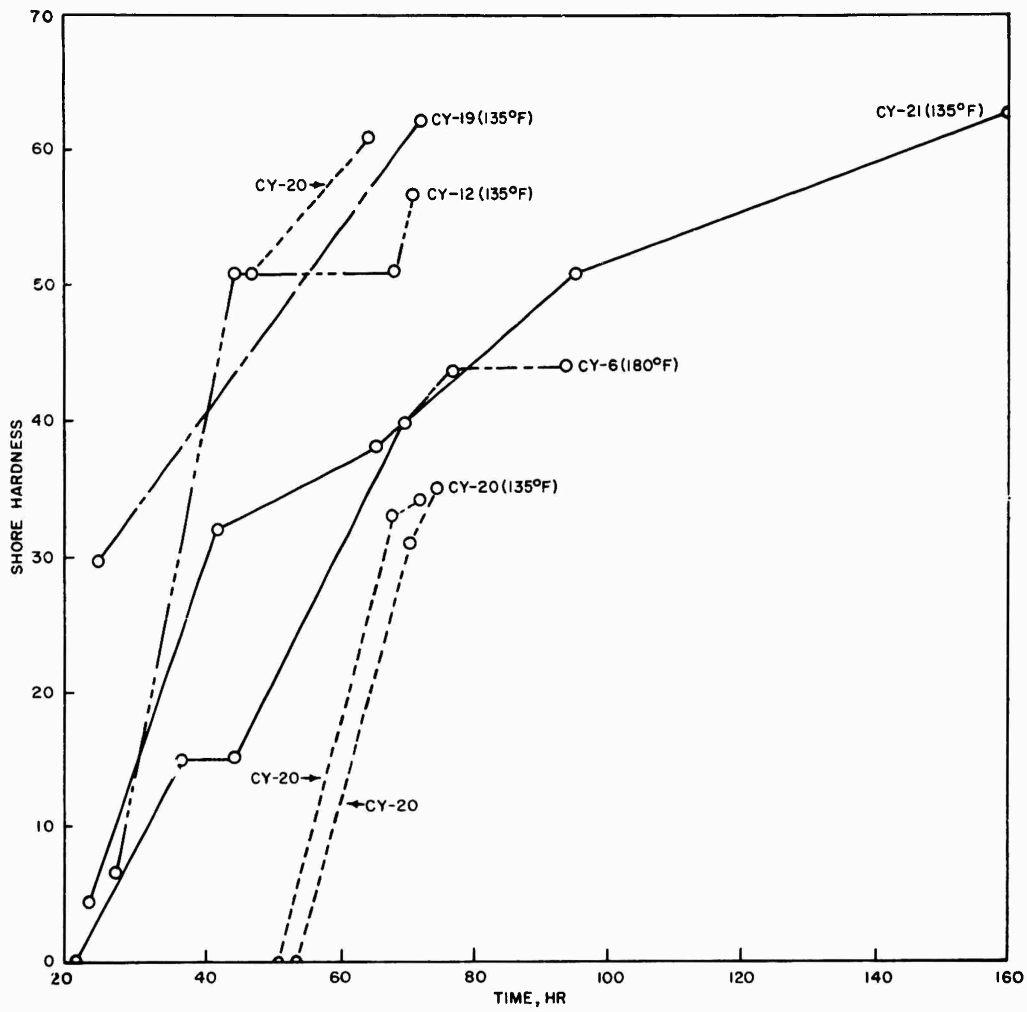


FIG. 28. Shore A-2 Durometer Hardness for a Number of Propellant Samples.

IGNITION

The modified Mk 264 pyrogen igniter fabricated for the initial three tests functioned so satisfactorily that the final igniter design evolved directly from it. These units consisted of a length of extruded cruciform magnesium-Teflon-Viton propellant, itself ignited by a booster charge of magnesium-Teflon mixed powders that was initiated by a Mk 3 squib (Fig. 29). The unit was attached to the 8-inch motor at the firing site and performed its role by a nozzled jet of flame directed onto the motor grain surface.

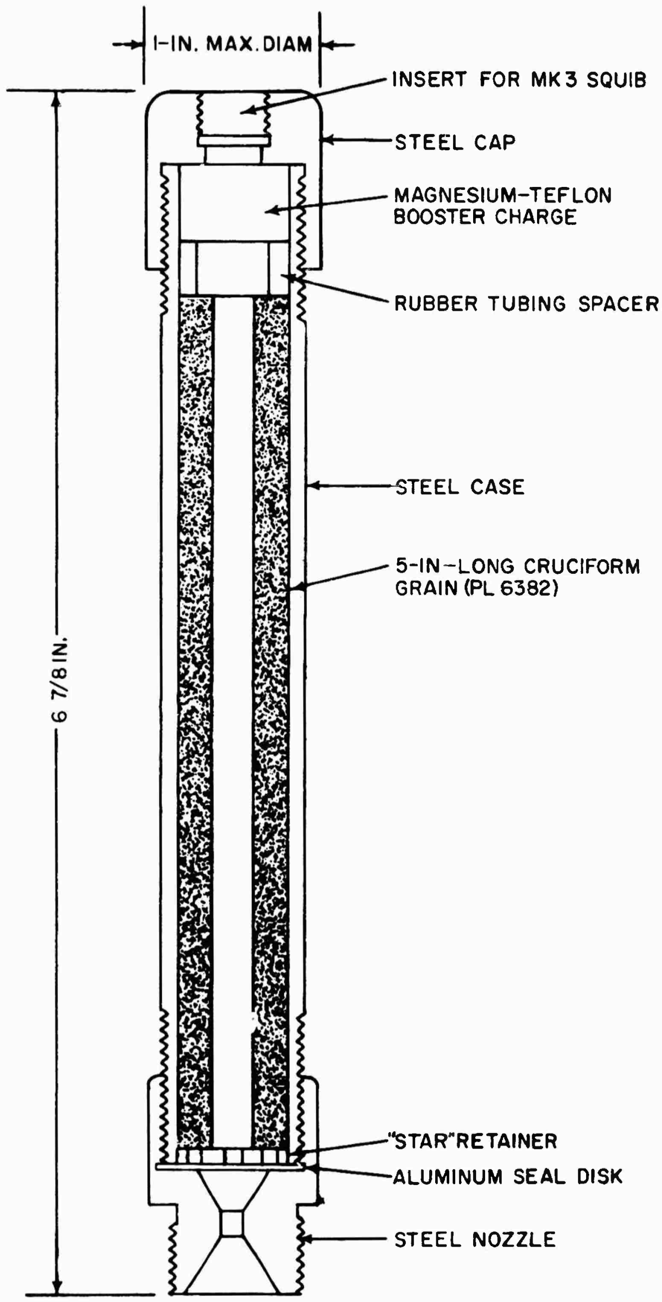


FIG. 29. Pyrogen Igniter for the Cyclops II.

DELIVERY PACKAGE

The Cyclops II unit had drag fins and an 8-inch outside-diameter motor package (Fig. 30). Since an end burner was desired for maximum duration, a single nozzle with short entrance and exit sections to maximize turbulence and minimize thrust was selected. (When the unit is dropped, the small thrust accelerates the motor downward during the fall.) Since no real data or close estimates of desired action time (time of drop from 40,000 to 15,000 feet) were available, crude estimates were used and the nozzle size selected from strand-burning-rate data and estimates of the discharge coefficient to give an operating pressure of approximately 200 psig.

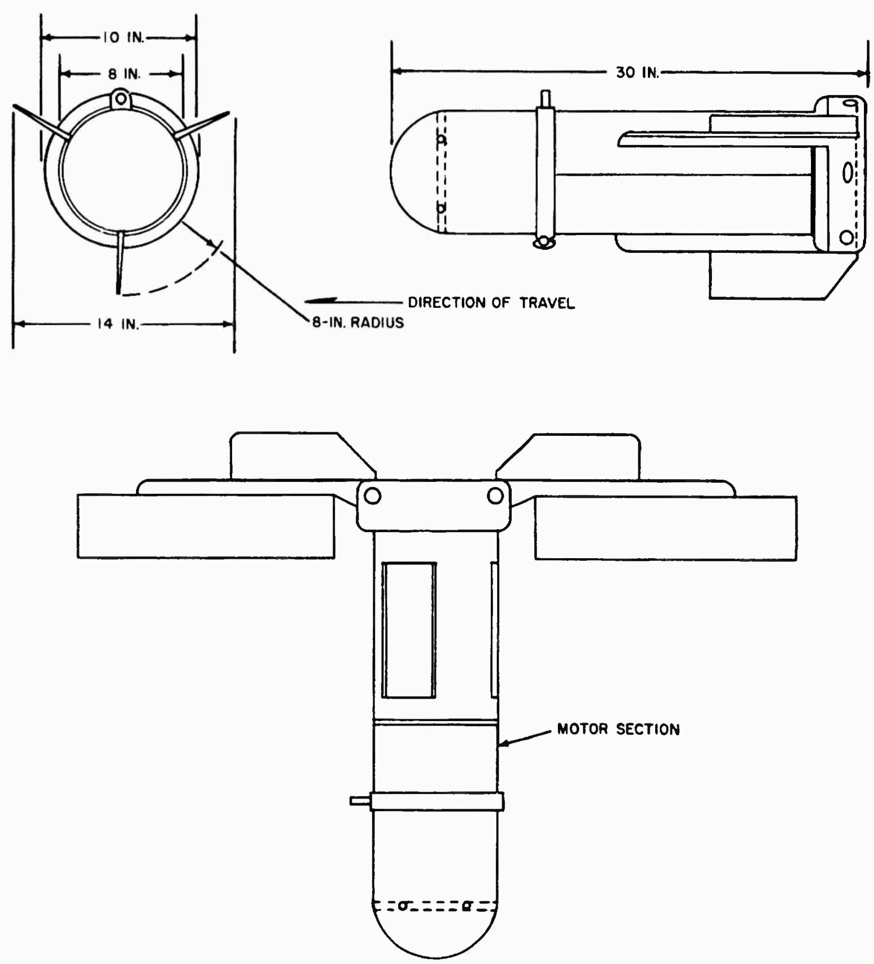


FIG. 30. Motor Package for the 8-Inch Cyclops II.

TESTING

Several sets of hardware (about 10) were fabricated to test the fin design and determine the drop rates. Three motor cases with nozzle inserts were supplied for propellant tests.

Static Tests. Table 4 is a summary of the static-firing results of the various 8-inch Cyclops II units. Pressure-thrust-time information is shown in Fig. 6-19. Figure 31 shows an 8-inch unit in a static-test stand.

Flight Tests. Initial flight tests of five units resulted in three failures. One of these was a reefer-cutter failure, which did not allow the drag fins to open. This resulted in a drop of 40,000 feet that was not retarded (see p. 10). Recovery of the other two units revealed that the magnetic-firing-current source, actuated by the drag fins, functioned but that the Mk 3 attachment adapter had been attached incorrectly, bending the center post to ground and shorting the igniter, which prevented the current from reaching the squib bridgewires.

Another flight test of four units from about 40,000 feet resulted in four completely satisfactory burns of about 90 seconds duration.

Twenty-four of these units were ready to ship to the magazines for transshipment and use against a hurricane on 12 September 1962.

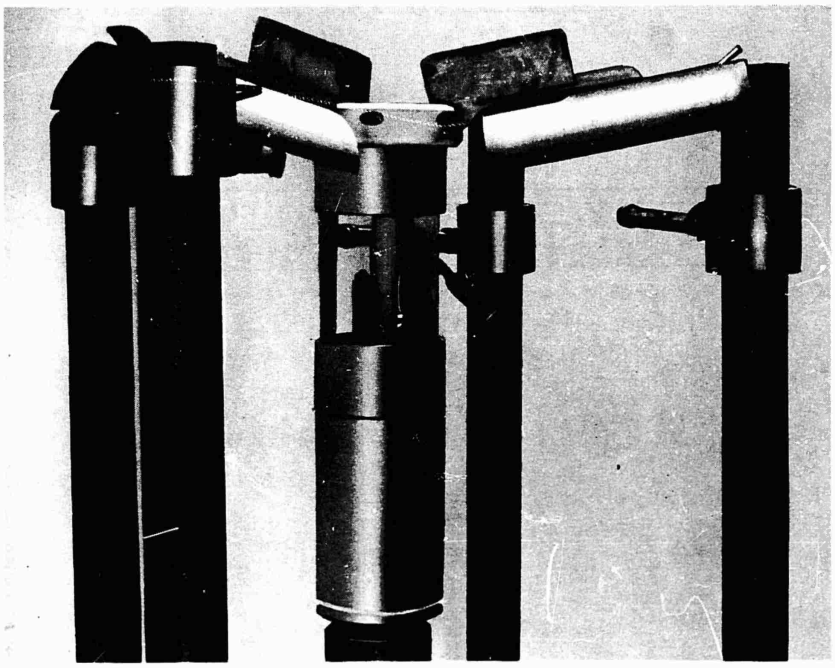


FIG. 31. 8-Inch Cyclops II Assembly in Static-Firing Stand.

CONCLUSIONS AND RECOMMENDATIONS

SCHEDULES

The original premise of a project to develop the best designs of delivery mode and hardware for two sizes of salt generator units over the span of a year, with prototype production to supply enough units for one full-scale test in a single hurricane, was drastically affected by the decision to supply units for the hurricane season of 1962.

Motor design, delivery-package design, and propellant-formulation studies had to be stopped and frozen before any evaluation could be started. The restriction against using Nitrasol propellants resulted in a much safer propellant with better physical properties, greater volumetric efficiency, and better processing properties to be used. This PBAA propellant was adapted from other propellant formulation studies currently under way at NOTS and in industry. Optimization and characterization could not be accomplished in the time allowed, but a large amount of data has been accumulated, particularly on CY-21, which tends to indicate that this propellant is optimum for use as a silver iodide generator. A characterization report should be generated and will necessitate gathering of some of the data necessary to make a better decision as to what is actually the best formulation. It is again emphasized that basic information is lacking in the knowledge of what is best for crystal formation and factors affecting this phenomenon are not known.

Also, no test method is available to characterize the rocket-exhaust products or the resultant materials after mixing with cold air. While the actual use of an item is a costly test method, it is the only one relied upon.

PROPELLANT PROCESSING

Extrusion of Nitrasol formulations is possible but physical integrity of the product is poor. Also, because of the Nitrasol ban, these propellants could not be processed. Fluorocarbon-based extruded or pressed grains can be made that yield very good tensile strengths. The data indicate that inhibiting is critical and that methods presently used may be marginal in effectiveness.

Mixing and casting of nitroplasticized PBAA propellants are believed possible in most conventional propellant-handling equipment used with the highly viscous state-of-the-art propellants.

ALECTO

It is believed that this 2 1/2-inch-diameter unit can be used more effectively than the large unit, except that an increased length would be much better, since longer action times could be easily realized. A ripple firing of these units could disperse equal amounts of silver iodide over a larger area than is possible with the large unit, allowing a great deal more versatility, which overlaps the range of the larger unit. Over-all volumetric efficiency and the inert-weight ratio are better, particularly if the reusable canister is not counted in the weight.

The major problem with the Alecto unit seems to be ignition reliability. It is believed that a canister ejection system designed exclusively for this unit with more desirable ignition methods will solve this problem. The design shown in Fig. 32 may prove satisfactory for future use. It would utilize exhaust gases from the igniter and grain to eject the motor from the canister.

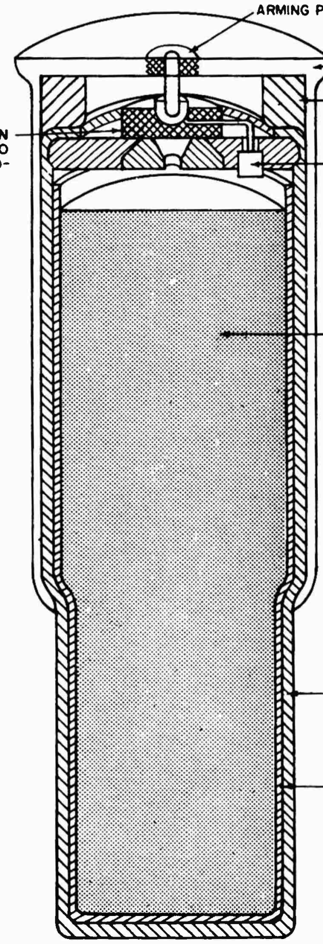


FIG. 32. Proposed Ignition–Ejection System for the 2 1/2-Inch Alecto.

CYCLOPS II

Experience with this unit was quite satisfactory in that all the objectives were met, and most of the tests were successful.

Introduction of several canted nozzles in place of the present nozzle could be utilized to bring about more widespread distribution of the exhaust. Proper orientation could be utilized to retard fall rate, induce spinning, or both. Also, a free-fall drop similar to that used with Alecto could be used by other grain designs, or higher internal pressures could be used to increase burning rate.

Motor weight could be reduced by a change to hemispherical or elliptical ends.

HEAT-BARRIER AND INHIBITOR LINERS

It is known that the heat-barrier system used is not optimum for several reasons. It is installed and cured in a manner not optimum for the material used, and it is of a much greater thickness than required. Thirty-thousandths of an inch thickness of any good heat-resistant phenolic resin in asbestos, pressure-cured and bonded to the steel motor tube, would function better and allow more propellant per motor.

The inhibitor liner "works" and was therefore used. Further studies of its properties and variations of formulation and cure as well as bonding tests should be conducted.

NEGATIVE NUMBERS OF ILLUSTRATIONS

Fig. 1, LHL L078811 (U)	Fig. 23-26, none
Fig. 2-19, none	Fig. 27, LHL L039000 (U)
Fig. 20, LHL L075932 (U)	Fig. 28-30, none
Fig. 21, LHL L076496 (U)	Fig. 31, LHL L076492 (U)
Fig. 22, LHL L075934 (U)	Fig. 32, none

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1 Naval Propellant Plant, Indian Head
2 Naval Underwater Ordnance Station, Newport
1 Naval Weapons Evaluation Facility, Kirtland Air Force Base (Code 401)
2 Naval Weapons Services Office
1 Operational Test and Evaluation Force
1 Bureau of Naval Weapons Branch Representative, Cumberland
1 Bureau of Naval Weapons Representative, Azusa, Calif.
1 Bureau of Naval Weapons Resident Representative, Sacramento
1 Navy Liaison Officer, Tactical Air Command, Langley Air Force Base

ABSTRACT CARD

U. S. Naval Ordnance Test Station
<u>Progress Report on Alecto and Cyclops II</u> (U), by <u>Ronald F. Vetter. China Lake, Calif., NOTS,</u> May 1963. 50 pp. (NAVWEPS Report 8074, NOTS TP 3091), CONFIDENTIAL.

ABSTRACT. This report covers work done on propellant formulations, motor design and testing, and igniter design for the Alecto and Cyclops II silver iodide-generating rocket motors.

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Tests were performed on only a few of each type of unit because the delivery schedules necessitated design freezes. However, static firings to check the ignition system, the heat liner system, and the inhibiting system were made. Some units were vibration-tested and others subjected to 5-foot-drop tests before firing.

All units showed that they were applicable for flight use, and 390 Alecto units and 24 Cyclops II units were ready for use against a hurricane by September 1962.

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